Chapter 8: Choosing Among Ink Technologies

CHAPTER CONTENTS

INTRODUCTION

Earlier chapters of this CTSA presented the findings of the research regarding risk, performance, cost, and resource requirements. This chapter takes a different look at some of that information. Section 8.1 summarizes the individual ink systems and product lines, using the solvent-based ink system as the baseline and providing comparisons to water-based and UV-cured inks. Performance tests, environmental and health impacts, and resource conservation are discussed.

Section 8.2 provides a qualitative social benefit-cost assessment of the different ink system, analyzing the private (printer) and social implications of the CTSA findings. Social costs and benefits are those that do not affect the flexographic facility directly, but that do affect the larger population and the environment. This viewpoint is one that is rarely considered within an industry setting.

Section 8.3 compares the three ink systems broadly. This section describes the chemical categories analyzed in the CTSA, and identifies the hazards and risks of each chemicals. Flexographic professionals can use this information to identify chemicals that they either may wish to avoid or that they may to use as safer alternatives.

8.1 SUMMARY BY INK SYSTEM AND PRODUCT LINE

Introduction

The results of the DfE Flexography Project, as shown in this CTSA, present information about several important factors that contribute to the selection of a flexographic ink. The performance, human and environmental risk, and operational costs associated with an ink are issues that a printer must consider when choosing among ink technologies. Though this research is not an exhaustive analysis of all flexographic inks, it provides an indication of how nine product lines of solvent-based, water-based, and UV-cured inks compare on wide-web film substrates. Individual printers will have conditions (and results) that vary from those encountered in this analysis, but the results in this report will be a starting point for determining how changes might affect the circumstances of a particular facility. Ink formulators also may gain from this analysis by learning how the hazards posed by chemicals in isolation translate into health and environmental risks when the chemicals are placed in the context an ink mixture used in a printing facility.

The DfE Flexography Project studied solvent-based, water-based, and UV-cured inks on three wide-web films: low-density polyethylene (LDPE), co-extruded polyethylene/ethyl vinyl acetate (PE/EVA), and oriented polypropylene (OPP). For each type of ink, between two and four specific product lines were tested. Table 8.1 indicates which substrates were used with each product line.

Table 8.1 Ink and Substrate Combinations

Product Line	Substrate
Solvent-based #1	OPP
Solvent-based #2	LDPE, PE/EVA, OPP
Water-based #1	OPP
Water-based #2	OPP
Water-based #3	LDPE, PE/EVA
Water-based #4	OPP
UV-cured #1	LDPE
UV-cured #2	LDPE, PE/EVA
UV-cured #3	PE/EVA

The performance chapter (Chapter 4) discussed the results of 18 tests on the nine product lines that were studied in the CTSA. Five of these tests were selected to highlight in this summary (Table 8.2).[1] These performance tests were selected because they were measured for all three systems; they display a range of important ink properties; and they were minimally dependent on external factors such as press equipment and operator expertise. Please see Chapter 4 for the results of the other performance tests.

Table 8.2 Selected Key Performance Indicators

Indicator	Description	Scale	Interpretation
Blocking	Measures the bond between ink and substrate when heat and pressure are applied. Ink transfer from a printed substrate to a surface in contact with the print indicates that blocking has occurred.	0-5	0 = no blocking and a good ink-substrate bond. 5 = complete blocking or removal
Gloss	Measures the reflected light directed at the surface from an angle. The test was only performed on LDPE and PE/EVA substrates, because gloss is irrelevant on laminated substrates (such as the OPP product in this project).	0-100	Higher numbers indicate higher reflectivity
Ice Water Crinkle	Measures the integrity and flexibility of the ink on the substrate when exposed to refrigerator and freezer conditions. The sample was submerged in a container of ice water for 30 minutes, then removed and twisted rapidly 10 times.	0-100	0 = intact ink finish 100 = complete removal of finish
Mottle	Measures the spottiness or non-uniformity of an ink film layer.	Open-ended	Lower values indicate a more consistent finish. Higher values indicate a more variable finish.
Trap	Measures the ability of an ink to adhere to an underlying ink. This trait is important where inks are printed on top of one another in order to generate precise color hues.	0-100%	100% = ideal

The **operating cost** information developed in this CTSA includes costs for materials, labor, capital, and energy, calculated per 6,000 square feet of image based on the methodology press speed of 500 feet per minute.

The **energy consumption** of each ink system is calculated per 6,000 square feet of image. Equipment included in this calculation includes hot air dryers, blowers, oxidizers, UV curing lamps, and corona treaters.

The results of the selected performance tests and the operating cost and energy consumption analyses are summarized in Table 8.3. Data for these three categories are presented for each product line (e.g., solvent-based ink #1), and also are averaged across the whole ink system. The solvent-based ink system is considered the baseline for this analysis; each water-based and UV-cured product line is compared to the baseline results in Table 8.3 through the use of ✰ (better than the baseline) or ✘ (worse than the baseline).

Table 8.4 summarizes the human health risks of each product line. Three categories of information are included in this table.

- **Range of chemicals with clear risk**: This column shows the total number of compounds with a clear health risk[a] to pressroom workers for each formulation in a product line. For example, if two chemicals with clear risk were found in one formulation of solvent-based #1, four were found in another formulation, and the other three formulations had numbers between these, the range would be 2-4. This range incorporates compounds that are expected to pose clear occupational risk to flexographers based on either toxicological studies or EPA's Structure Activity Team (SAT) assessments.

- **Chemical categories with clear risk**: Lists the chemical categories that presented clear inhalation risk to pressroom workers and clear dermal risks to press- and prep-room workers. Superscripts next to each category name indicate whether the compounds presented a clear risk through inhalation (inhal) or dermal (derm) exposure. Categories are denoted with "(SAT)" if the compound with clear risk was analyzed by the SAT. An SAT evaluation is considered to be a less accurate measurement method than toxicological information. (See explanation in Chapter 3: Risk.)

- **Toxicological endpoints:** In toxicological tests, researchers record observed effects of the given chemical. These qualitative observations, called toxicological endpoints, indicate effects that have been associated with compounds in formulations in each of the respective product lines. The information is separated based on the exposure route, because effects may be different depending on whether a compound is absorbed dermally or by inhalation. Toxicological endpoints can be useful for highlighting the scope of potential human health effects of the ink systems. The user of flexographic inks should be aware that the risk of health effects may be present with *any* ink. *Toxicological endpoints provide an indication of such potential effects, but only offer a broad perspective.* "Liver effects," for example, may range in significance from liver enlargement to cirrhosis or changes in liver cells that may lead to the growth of tumors. The first effect may have little practical importance, but the latter may jeopardize survival. *The table does not indicate the severity of effects, nor does it imply that all of the effects would be observed at the exposure levels in typical flexographic prep or press rooms.*

Table 8.5 presents indicators of safety and environmental concerns associated with each product line.

- **Safety information:** Three categories of safety hazards are included: reactivity, flammability, and ignitability. Reactivity and flammability are based on scales of 0-4; 0 indicates that a compound is stable and will not burn, respectively, and 4 indicates that it is readily explosive or flammable. Ignitability is characterized as yes or no; a compound is ignitable if it has a flashpoint below 140°F.

- **Smog-related emissions:** The flexographic printing process emits pollutants that cause smog in two ways. First, VOCs are released directly from the ink formulations as ink is applied to the substrate. Second, VOCs, nitrogen oxides, and carbon

[a]Clear risk indicates that there is an inadequate level of safety for the chemical in question under the assumed exposure conditions, and that adverse effects can be expected. See Section 3.7 of the Risk chapter for more information about risk rankings.

monoxide are produced during the production of the electricity and heat used in printing.

- **Ink content:** Two important indicators of possible air impacts are the concentration of VOCs and HAPs. The concentrations of both were taken from the ink MSDSs and averaged across each formulation within each product line.

Table 8.3 Summary of CTSA Competitive Tests

Product Line	Performance					Cost	Energy
	Blocking (0=none)	Gloss (100= maximum)	Ice Water Crinkle (0%=intact)	Mottle (lower=more desirable)	Trap (100%= optimum)	Total Cost per 6,000 ft^2 of Image[a]	Btu per 6,000 ft^2 of image
Baseline: Solvent-based Ink System							
Solvent-based #1	1.8	NA[b]	NA	192	101%	$31.89	100,000
Solvent-based #2	2.7	53.0	0%	217	98%	$34.06[c]	100,000
Average across Solvent-based Inks	*2.3*	*53.0*	*0%*	*205*	*100%*	*$32.98*	*100,000*
Range across Solvent-based Inks	*1.8-2.7*	*53.0*	*0%*	*192-217*	*98-101%*	*$31.89-$34.06*	*100,000*
Alternative 1: Water-based Ink System							
Water-based #1	4.0	NA	NA	592	90%	$30.04	73,000
baseline comparison	✘[d]	NA	NA	✘	✘	✰	✰
Water-based #2	3.0	NA	NA	186	87%	$26.78	73,000
baseline comparison	✘	NA	NA	✰	✘	✰	✰
Water-based #3	1.3	46.5	Partial removal on 8 of 22 samples	478	93%	$25.36[c]	73,000
baseline comparison	✰	✘	✘	✘	✘	✰	✰
Water-based #4	2.5	NA	NA	115	89%	$24.23	73,000
baseline comparison	✘	NA	NA	✰	✘	✰	✰
Average across Water-based Inks	2.7	46.5	36%	342	90%	$26.60	73,000
baseline comparison	✘	✘	✘	✘	✘	✰	✰
Range across Water-based Inks	1.5-4.0	46.5	36%	115-592	87-93%	$24.23-$30.04	73,000

	Performance					Cost	Energy
Product Line	**Blocking (0=none)**	**Gloss (100= maximum)**	**Ice Water Crinkle (0%=intact)**	**Mottle (lower=more desirable)**	**Trap (100%= optimum)**	**Total Cost per 6,000 ft^2 of Image[a]**	**Btu per 6,000 ft^2 of image**
New Developing Technology: UV-Cured Ink System							
UV-cured #1	1.0	32.3	0%	271	82%	$51.00	78,000
baseline comparison	✰	✘	*(even)*	✘	✘	✘	✰
UV-cured #2	2.1	47.0	Partial removal on 8 of 8 samples	205	90%	$35.78[c]	78,000
baseline comparison	✰	✘	✘	*(even)*	✘	✘	✰
UV-cured #3	1.0	35.9	0%	273	95%	$23.69[c]	78,000
baseline comparison	✰	✘	*(even)*	✘	✘	✰	✰
Average across UV-cured Inks	1.4	38.4	33%	250	89%	$36.82	78,000
baseline comparison	✰	✘	✘	✘	✘	✘	✰
Range across UV-cured Inks	1.0-2.1	32.3-47.0	0-100%	205-273	82-95%	$23.69-$51.00	78,000

[a] Costs are based on the methodology press speed of 500 feet per minute.
[b] NA indicates the test was not performed on the product line.
[c] This product line was printed on PE/EVA for some or all of its performance demonstrations; because this substrate did not require the use of white ink, costs may be lower than expected.
[d] ✰ Indicates better than baseline; ✘ Indicates worse than baseline.

Table 8.4 CTSA Occupational Health Information For Each System and Product Line

Product Line	Risk: Chemicals with Clear Occupational Risk — Range (No.)[a]	Risk: Chemicals with Clear Occupational Risk — Chemical Categories[b]	Toxicological Endpoints: Dermal	Toxicological Endpoints: Inhalation
Baseline: Solvent-based Ink System				
Solvent-based #1	2-4	alcohols[inhal,derm], alkyl acetates[inhal,derm], inorganics[derm], organic acids or salts[derm], organometallic pigments (SAT)[derm], organotitanium compounds (SAT)[derm]	bile duct, blood, bone, bone marrow, developmental, endocrine, eye, g.i., heart, hormone, immune, kidney, liver, lymphatic, pancreatic, neurotoxic, rectal, reproductive, respiratory, and skin effects; increased mortality; altered body and organ weights; decreased survival; changes in serum chemistry and blood pressure	blood, bone marrow, developmental, eye, g.i., heart, kidney, liver, neurotoxic, reproductive, respiratory, spleen, and thymus effects; altered organ weights; changes in enzymes, clinical, serum, and urine chemistry; changes in blood pressure; decreased growth
Solvent-based #2	2-4	alcohols[inhal,derm], hydrocarbons – low molecular weight[inhal], organometallic pigments (SAT)[derm]	bile duct, blood, bone, developmental, endocrine, g.i., heart, hormone, immune, liver, lymphatic, neurotoxic, pancreatic, rectal, reproductive, respiratory, skin, and spleen effects; altered body and organ weights; decreased survival; increased mortality; changes in clinical chemistry	auditory, blood, bone marrow, developmental, liver, neurotoxic, reproductive, respiratory; spleen, thymus effects; altered serum chemistry; changes in enzymes, clinical, and urine chemistry; decreased growth
Average across Solvent-based Inks	3.2			
Range across Solvent-based Inks	2-4			

Product Line	Risk		Toxicological Endpoints	
	Chemicals with Clear Occupational Risk		Dermal	Inhalation
	Range (No.)[a]	Chemical Categories[b]		
Alternative 1: Water-based Ink System				
Water-based #1	2-4	alcohols[inhal,derm], amides or nitrogenous compounds[inhal,derm], ethylene glycol ethers[inhal,derm], organic pigments[derm]	bile duct, blood, bone, bone marrow, developmental, eye, kidney, liver, lymphatic, neurotoxic, respiratory, skin, and stomach effects; altered organ weights; decreased body weight; decreased survival; benign skin tumors	eye, liver, neurotoxic, reproductive, respiratory, skin, and spleen effects; benign skin tumors; changes in enzymes, clinical, and urine chemistry
baseline comparison	*(even)*			
Water-based #2	2-4	alcohols[inhal], amides or nitrogenous compounds[inhal,derm], ethylene glycol ethers (SAT)[derm]	bile duct, bladder, blood, blood chemistry, bone, bone marrow, kidney, liver, lymphatic, neurotoxic, reproductive, respiratory, and spleen effects; altered organ weights; decreased survival; decreased food consumption; changes in enzyme levels	bladder, blood, blood chemistry, corneal, developmental, kidney, liver, neurotoxic, reproductive, respiratory, spleen, effects; changes in enzyme levels; altered body weights
baseline comparison	*(even)*			
Water-based #3	1-4	alcohols[inhal,derm], amides or nitrogenous compounds[inhal,derm], ethylene glycol ethers[inhal,derm], organometallic pigments[derm]	bile duct, blood, blood chemistry, bone, bone marrow, developmental, eye, kidney, liver, lymphatic, neurotoxic, reproductive, respiratory, skin, spleen, and thymus effects; altered organ weights; decreased survival; decreased body weight; changes in clinical chemistry	bladder, blood, corneal, enzyme, eye, kidney, liver, neurotoxic, reproductive, respiratory and spleen effects; altered organ weights; changes in enzymes, clinical and urine chemistry;
baseline comparison	☆			
Water-based #4	3-4	alcohols[inhal,derm], amides or nitrogenous compounds[inhal,derm], organometallic pigments[derm]	bile duct, blood, bone, bone marrow, clinical chemistry, developmental, eye, kidney, liver, lymphatic, neurotoxic, respiratory, skin, and thymus effects; altered body and organ weights; decreased survival; increased mortality	corneal, developmental, eye, kidney, liver, neurotoxic, reproductive, respiratory, and spleen effects; changes in enzymes, clinical, and urine chemistry; decreased growth; altered body and organ weights
baseline comparison	✘			

Table 8.4 CTSA Occupational Health Information For Each System and Product Line (continued)

	Risk		**Toxicological Endpoints**	
Product Line	**Chemicals with Clear Occupational Risk**		**Dermal**	**Inhalation**
	Range (No.)[a]	**Chemical Categories[b]**		
Average across Water-based Inks	3.1			
baseline comparison	☆			
Range across Water-based Inks	1-4			
New Developing Technology: UV-Cured Ink System				
UV-cured #1	1-2	acrylated polymerrs (SAT)[derm], amides or nitrogenous compounds(SAT)[inhal,derm], inorganic pigments (SAT)[derm], organometallic pigments[derm]	bile duct, developmental, lymphatic, respiratory, and thymus effects; altered body and organ weights; changes in clinical chemistry	developmental effects
baseline comparison	☆			
UV-cured #2	4-5	acrylated polymers (SAT)[inhal,derm], acrylated polyols[inhal,derm], organometallic pigments[derm], organophosphorous compounds[derm]	adrenal, bile duct, blood, developmental, enzyme, eye, kidney, liver, lymphatic, neurotoxic, reproductive, respiratory, skin, and thymus effects; altered body and organ weights; changes in serum and clinical chemistry; decreased body weight	developmental, liver, respiratory effects; altered organ weights
baseline comparison	✘			
UV-cured #3	1-2	acrylated polymers (SAT)[derm], acrylated polyols (SAT)[inhal,derm], amides and nitrogenous compounds (SAT)[inhal,derm]	bile duct, blood, lymphatic, reproductive, respiratory, and skin effects; altered body weights; decreased body weight	None identified
baseline comparison	☆			

Product Line	Risk		Toxicological Endpoints	
	Chemicals with Clear Occupational Risk		Dermal	Inhalation
	Range (No.)[a]	Chemical Categories[b]		
Average across UV-cured Inks	2.4			
baseline comparison	✰			
Range across UV-cured Inks	1-5			

[a] Indicates the range in the number of compounds with clear worker health risk per formulation within each product line.
[b] Chemical categories listed in this column appear in at least one of the five formulations in the respective product lines.
inhal = clear worker risk via inhalation exposure; derm = clear worker risk via dermal exposure

Table 8.5 CTSA Environmental and Safety Findings For Each System and Product Line

	Safety Hazard			Smog-Related Emissions			Ink Content[g,h]	
Product Line	**Reactivity[a] (0-4)**	**Flammability[a] (0-4)**	**Ignitability[b] (yes/no)**	**Ink-Related VOC Emissions[e] (g/6,000 ft^2)**	**Energy-Related Emissions[f] (g/6,000 ft^2)**	**Total Smog-related Emissions (g/6,000 ft^2)**	**Average VOC content (%)**	**Average HAP Content (%)**
Baseline: Solvent-based Ink System								
Solvent-based #1	0	3	yes	667 (1991)	90	757 (2081)	62	0
Solvent-based #2	0	3	yes	980 (2925)	90	1070 (3015)	54	0
Average across Solvent-based Inks	0	3	yes	824 (2458)	90	914 (2548)	58	0
Range across Solvent-based Inks	0	3	yes	667-980 (1991-2925)	90	757-1070 (2081-3015)	54-62	0
Alternative 1: Water-based Ink System								
Water-based #1	0	1-3	no	250	63	313	9	3.4
baseline comparison	*(even)*	✩	✩	✩	✩	✩	✩	✘
Water-based #2	0	0-1	no	110	63	173	1	0.72
baseline comparison	*(even)*	✩	✩	✩	✩	✩	✩	✘
Water-based #3	0	1	no	135	63	198	1	0.14
baseline comparison	*(even)*	✩	✩	✩	✩	✩	✩	✘
Water-based #4	0	0-3	no	138	63	201	14	0
baseline comparison	*(even)*	✩	✩	✩	✩	✩	✩	*(even)*
Average across Water-based Inks	0	1.7	no	158	63	221	6.3	1.1
baseline comparison	*(even)*	✩	✩	✩	✩	✩	✩	✘
Range across Water-based Inks	0	0-3	no	110-250	63	173-313	1-14	0-3.4

Product Line	Safety Hazard			Smog-Related Emissions			Ink Content[g,h]	
	Reactivity[a] (0-4)	Flammability[a] (0-4)	Ignitability[b] (yes/no)	Ink-Related VOC Emissions[e] (g/6,000 ft^2)	Energy-Related Emissions[f] (g/6,000 ft^2)	Total Smog-related Emissions (g/6,000 ft^2)	Average VOC content (%)	Average HAP Content (%)
New Developing Technology: UV-Cured Ink Systems								
UV-cured #1	NA[c]	NA[d]	no	77	110	187	1[i]	0
baseline comparison	NA	NA	☆	☆	✘	☆	☆	*(even)*
UV-cured #2	1	1	no	413	110	523	1	0
baseline comparison	✘	☆	☆	☆	✘	☆	☆	*(even)*
UV-cured #3	NA	NA	no	81	110	191	1	0
baseline comparison	NA	NA	☆	☆	✘	☆	☆	*(even)*
Average across UV-cured Inks	1	1	no	190	110	300	1	0
baseline comparison	✘	☆	☆	☆	✘	☆	☆	*(even)*
Range across UV-cured Inks	1	1	no	77-413	110	187-523	1	0

Footnotes for Safety Hazard columns
[a] Scale of 0-4, in order of increasing hazard. See Chapter 2: Introduction for details on the rating scales.
[b] A formulation is classified as ignitable if it has a flashpoint below 140°F.
[c] Incomplete data — reactivity information was only available for UV-cured #2.
[d] Incomplete data — flammability information was only available for UV-cured #2.
Footnotes for Smog-related Emissions
[e] Includes calculated releases from inks, solvents, and additives. For solvent-based ink systems, assumes the use of a control system with a 70% capture efficiency and a 95% efficient control device (oxidizer). Solvent-based emissions calculated without an oxidizer are listed in parentheses.
[f] Includes carbon monoxide, hydrocarbons, and nitrogen oxides released by electric utilities and natural gas-fired oxidizers and ovens. Only includes emissions from power consumption due to curing/drying, emission control, and corona treaters. Represents total load of smog forming chemicals, not smog formation potential. The latter will vary depending on the mix of pollutants, shown in Table 6-18 in the Resource Conservation chapter, and atmospheric/meteorological conditions.
Footnotes for Ink Content columns
[g] Content percentages are calculated by weight.
[h] VOCs and HAPs may overlap between columns.
[i] UV-cured VOC content was calculated based on the post-cured composition.

Solvent-based Inks

Solvent-based inks were considered the baseline for this analysis because they traditionally are used by the most printers. There were two solvent-based product lines. Solvent-based ink #1 was used with OPP at one facility, and solvent-based ink #2 was used with all three substrates (LDPE, PE/EVA, and OPP) at three facilities.

Performance
Solvent-based inks performed relatively well on each performance test. The **blocking resistance** test produced results that were not ideal, but were acceptable in most cases. Solvent-based ink #1, printed in OPP, displayed a result of 1.8 (between slight cling and cling). Solvent-based ink #2 displayed an average result of 2.7 (between cling and slight blocking). For Solvent-based ink #2, the results may have been affected by facility-specific conditions. The eight samples taken at Facility 5 (four each on LDPE and PE/EVA) yielded an average score of 2.1. In contrast, the results at Facility 7 (also four samples each on LDPE and PE/EVA) had an average score of 3.6 (between slight blocking and considerable blocking).

Gloss was measured for solvent-based ink #2, which was printed on LDPE and PE/EVA. For this product line, the average gloss was 53. Within these results, the values appear to have been affected by both substrate and facility conditions. The ink appeared to produce a glossier finish on PE/EVA; the average value on this substrate was 59 in comparison to the average 51 on LDPE. Also, higher gloss was found at Facility 7 than Facility 5; the average values were 57 and 51, respectively.

The **ice water crinkle** test was performed with solvent-based ink #2. All samples of this ink resisted removal during this test, resulting in a 0% removal rate. These results indicated that this solvent-based ink would be appropriate for use in cold, wet conditions.

Mottle was measured for both solvent-based inks. Solvent-based inks #1 and #2 had values of 192 and 217, respectively, on the mottle scale. Though mottle does not have an industry standard, these values were lower than those for the other two ink systems. It should be noted, however, that although the average mottle rating for the two product lines were similar, there was significant variation between the two measured formulations within each product line. Blue inks were much more mottled than green inks. This difference was consistent across all substrates and facilities.

Trap measurements for both solvent-based product lines were consistently near 100%. The two solvent-based inks attained near-complete trapping; i.e., the top ink adhered to the underlying ink as well as it did to exposed substrate.

Overall, the solvent-based inks performed quite well in these tests. They exhibited good physical characteristics through the blocking, ice water crinkle, and trap tests, and displayed comparatively good visual results in the gloss and mottle tests. For more detail on these tests or others, please see Chapter 4: Performance.

Environmental and Health Impacts
Table 8.4 shows the number of chemicals with clear worker risk for each formulation within the solvent-based product lines (presented as a range). In addition, the table lists the chemical

categories that present clear pressroom worker health risk, and identifies the exposure route of concern for each.

In the **occupational risk** assessment, solvent-based ink #1 contained between two and four chemicals with clear occupational risk in each formulation. All chemicals of concern presented a dermal risk, and two categories (alcohols and alkyl acetates) also presented a clear occupational risk via inhalation. Solvent-based ink #2 also had between two and four chemicals with clear risk in each formulation. Three chemical categories presented clear risk: alcohols presented clear risk via both dermal and inhalation exposure, low molecular weight hydrocarbons presented a clear risk via inhalation exposure, and organometallic pigments presented risk via dermal exposure.

Across both product lines, the inhalation risk stems from chemical categories that are solvents and multiple-function compounds. The compounds presenting clear dermal risk are solvents, colorants, additives, and compounds listed as multiple-function.

The toxicological endpoints column of Table 8.4 presents possible health impacts of these chemicals with clear risk. For solvent-based inks, health effects are possible via both dermal and inhalation exposure.

The **safety hazards** of the solvent-based inks, as presented in Table 8.5, included significant rankings for both flammability and ignitability. The flammability score of 3 indicated that the ink could be easily ignited under almost all normal temperature conditions and that water may be ineffective in controlling or extinguishing such a fire. Both product lines also were ignitable, indicating that they had a flashpoint (the lowest temperature at which vapor is sufficiently concentrated that it can ignite in air) below 140°F.

Table 8.5 shows estimated **air emissions** of smog-related air releases resulting from inks and energy use. Although the estimates for the solvent-based product lines assumed that an oxidizer would be used to control emissions from the inks, the assumed capture efficiency was only 70%. This resulted in a relatively high amount of uncaptured emissions, so that overall, the two product lines were estimated to release 757 and 1,070 grams of smog-related emissions per 6,000 ft^2 of image, respectively. Emissions from solvent-based presses with an oxidizer may vary; they can be lower if the capture efficiency is better, but emissions may be higher if the oxidizer is not operated optimally and consistently.

Table 8.5 indicates that, as expected, both solvent-based inks have a relatively high **VOC content**, at an average of 58% by weight. Neither product line contained any chemicals designated as HAPs.

Operating Costs

The operating costs associated with using these solvent-based inks are shown in Table 8.3. The costs of ink, labor, capital, and energy per 6,000 square feet of substrate (at a press speed of 500 feet per minute) were expected to be $31.89 for solvent-based ink #1 and $34.06 for solvent-based ink #2.

For both of these product lines, the ink costs were the highest expense (between $14 and $24 per 6,000 ft^2, depending on the consumption rate at the individual performance demonstration sites). Capital costs were the second-largest component of the operating costs, at $11.87 per

6,000 ft^2, and labor and energy the least significant part of overall cost, at \$5.29 and \$0.53 per 6,000 ft^2, respectively.

Two factors drove the operating costs of solvent-based ink relative to the other two ink systems. First, this system required the use of an oxidizer. This component added approximately \$128,000 to the capital cost of the press, which in turn increased the per-hour capital cost by \$3.80, assuming a 15% annual depreciation rate over 20 years. Second, the high evaporation rate of solvent from solvent-based inks required the press-side addition of additional solvent. This led to a high rate of press-side solvent consumption.

Some factors were not considered in this analysis that may affect the cost of solvent-based inks, as well as water-based and UV-cured inks. These include the ability of an ink to print at higher press speeds, ink monitoring requirements, and cleaning difficulties. Factors such as these may vary among ink systems and alter their relative costs.

Resource Conservation

Energy use was the highest for solvent-based ink, at 100,000 Btu per 6,000 ft^2 of image. The dryers and associated blowers were the most significant consumers of energy, consuming approximately 460,000 Btu/hour, or 55,000 Btu/6,000 ft^2. The oxidizer accounted for much of the remaining energy demand. It should be noted, however, that it has become more common to recirculate exhaust from the oxidizer into the dryers. This practice lowers energy requirements for the dryers so that the net effect on energy use by adding an oxidizer is minimal.

Ink consumption, as discussed in the operating cost summary above, also was relatively high. Based on performance demonstrations excluding those on PE/EVA (for which white ink was not used), an average of 7.07 lbs/6,000 ft^2 of solvent-based ink was consumed, and an average of 2.48 lbs/6,000 ft^2 of additives were used. This high consumption rate is due to the relatively low solids content of solvent-based inks, which in turn necessitates anilox rolls with larger volumes.

Summary of Solvent-based Inks

The solvent-based inks performed well on the performance tests, but they had liabilities with respect to worker health risks, safety hazards, operating costs, and the consumption of ink and energy.

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- This system produced ideal results on the ice water crinkle and trap tests, and produced comparatively good results on the blocking, gloss, and mottle tests (for which no industry standards are available).
- The formulations in both product lines contained chemicals with clear worker risk for both inhalation and dermal exposure routes, presented both flammability and ignitability characteristics, and had high VOC emissions despite the use of oxidizers.
- Operating costs were relatively high, due to the required use of oxidizers and higher ink consumption rates.
- Ink and press-side additive consumption rate was high, due to the high evaporation rates of solvents.
- Energy consumption was high, because of the added energy demands of oxidizers.

Water-based Inks

Four water-based inks were tested in this analysis. Water-based inks #1 and #2 were tested on OPP at one facility each. Water-based #3 was tested on LDPE and PE/EVA at two sites. Water based ink #4 was tested on OPP at one site.

Performance

The results varied considerably among water-based product lines. **Blocking** was one of the tests in which the results were inconsistent across the product lines. Water-based ink #1 displayed the worst results, with an average score of 4.0 (considerable blocking). Water-based inks #2 and #4 performed slightly better, with scores of 3.0 and 2.5 (slight blocking and between cling and slight-blocking), respectively. Water-based ink #3 performed quite well, with an average score of 1.3 (between slight cling and cling). Unlike for the solvent-based inks, the results did not appear to be facility-specific. Water-based ink was used at both Facility 2 and Facility 3; at each, the average value was 1.3. The system as a whole compared unfavorably to the results for the solvent-based inks for blocking resistance.

Gloss was measured for water-based ink #3, the one product line tested on LDPE and PE/EVA. The average measurement was 46.5, which was somewhat lower (i.e., less desirable) than the average for solvent-based inks. Like for the solvent-based inks, the results seemed to be influenced by the substrate; on LDPE, the average gloss was 42.3, and on PE/EVA, the average gloss was 54.1. Overall, this water-based product line did not provide quite as glossy a finish as the solvent-based inks that were tested.

Ice water crinkle was also only tested for water-based ink #3. Of the 16 samples tested, part of the coating was partially removed on five of them. In each case, only a small fraction (about 5%) of the coating was removed; most of this removal was associated with the blue and green formulations. The results appeared to be facility-specific; no removal was observed at Facility 2. At Facility 3, however, five of the eight samples had some removal (including all four samples on LDPE). These results were worse than the solvent baseline, with which no removal was observed.

The **mottle** results also showed a wide range among the product lines. Water-based inks #1 and #3 had scores of 592 and 478, respectively, which were much higher (worse) than those for solvent-based inks. In contrast, the scores for water-based inks #2 and #4 were 186 and 115, respectively — comparable or much lower than those for the solvent-based inks. Overall, the mottle scores for water-based inks were higher (worse) than the solvent baseline. Like for the solvent-based inks, the blue water-based inks overall were much more mottled than the green inks.

The water-based inks had fairly consistent scores for **trapping** – between 87 and 93%. The results may have been facility-specific; at Facility 2 (using water-based ink #3 on LDPE and PE/EVA), the average was 84% and at Facility 3 (also using ink #3 on LDPE and PE/EVA), the average score was 101.5%.

Overall, the performance of the water-based inks was marked by inconsistency. In several cases, such as blocking resistance with water-based ink #3 and mottle with inks #2 and #4, the inks produced results better than those seen for either of the solvent-based inks. However, several tests of the water-based inks produced results worse than the baseline. In addition, there was variation between facilities using the same product line and substrates for the ice water crinkle and trap tests. The results may indicate that it is possible for water-based inks to obtain or exceed the level of performance of solvent-based inks for some parameters, but that it may be necessary to match the ink closely to the substrate being printed and to control other operating conditions carefully.

Environmental and Health Impacts

In the **occupational risk** assessment, the water-based product lines, as indicated in Table 8.4, had between one and four chemicals with clear worker health risk in each formulation. Water-based inks #1 and #2 both had the same range of chemicals with clear risk as the solvent-based inks — between two and four. The range for water-based ink #3 was between one and four, and that for ink #4 was between three and four chemicals with clear risk per formulation.

In each product line, alcohols and amides or nitrogenous compounds produced clear worker risk via dermal exposure and in most cases via inhalation as well. Other chemical categories with clear risk included ethylene glycol ethers, organic pigments, and organometallic pigments. The risk in these water-based inks, therefore, arose from solvents, pigments, and multiple-function compounds.

Table 8.4 presents toxicological endpoints associated with compounds in the water-based inks. As with the solvent-based inks, effects may occur both via dermal and inhalation exposure.

The **safety hazard** characteristics of the water-based inks in this analysis were variable, as indicated in Table 8.5. None were reactive or ignitable. Likewise, for flammability, water-based inks #2 and #3 both had ratings of 0 or 1. In contrast, however, water-based inks #1 and #4 had flammability ratings of 3 for some formulations. This difference illustrates that despite the common classification as "water-based", the content of flammable solvents can vary considerably.

The **VOC content** data also demonstrate the differences among product lines. In Table 8.5, inks #1 and #4 were comprised of 9 and 14% VOCs by weight, respectively. Printers who use water-based ink to comply with the Clean Air Act generally use inks with less than 4% VOC content and minimize their use of VOC press-side solvents and additives. It should be noted, however, that although product lines #2 and #3 contain only small levels of VOCs (1% in each), they also contain small concentrations of HAPs.

Table 8.5 presents the estimated smog-related **air emissions** associated with the use of water-based inks. Despite the lack of an oxidizer, emissions were calculated to be considerably lower than those for the baseline. Inks and press-side materials were expected to release between 110 and 250 grams per 6,000 ft^2, with another 63 grams released due to energy consumption.

Overall, the risk associated with water-based inks is quite variable. Water-based inks #2 and #3 had an equal or lower number of chemicals with clear worker health risk compared to the baseline, had flammability ratings of 1, and had among the lowest releases of smog-related compounds of the three systems. In contrast, water-based inks #1 and #4 had an equal or higher number of chemicals with clear risk compared to the baseline, had flammability ratings that for several formulations were equal to that of the baseline, and produced high levels of smog-related compounds. It is clear, then, that the risks associated with these water-based inks were very much formulation-specific.

Operating Costs

For all product lines, water-based ink was less expensive than the baseline. The costs for materials, labor, capital and energy ranged between \$24 and \$30 per 6,000 ft^2 of image, but on average the water-based inks were \$6.40 less expensive to use than the solvent-based inks. Two effects were responsible for this difference: the lack of an oxidizer and the lower consumption of ink and press-side fluids.

The oxidizer generates a strain both on capital and energy costs. As discussed in the solvent-based ink summary, an oxidizer used on two presses may cost approximately \$250,000 to purchase and install. In addition, depending on the amount of solvent loading, energy costs for the oxidizer can be approximately \$2.11 per hour, or \$0.25 per 6,000 ft^2 of image.

In addition, the ink and additive costs were lower for water-based inks. The per-pound price of water-based inks was actually higher: \$1.60 and \$3.00 per pound for white and colored water-based inks, respectively, compared to \$1.40 and \$2.80 per pound for the solvent-based inks. However, the consumption rate was considerably lower for water-based inks, which led to the overall lower costs.

Resource Consumption

As indicated in Table 8.3, energy consumption was the lowest for water-based inks. Among the gas-heated air dryer and electric blower and corona treater, the water-based inks were expected to demand 610,000 Btu/hour, or 73,000 Btu/6,000 ft^2 of substrate. The dryers were expected to consume considerably more energy than those for solvent-based ink (500,000 Btu/hour for the water-based inks compared to 360,000 Btu/hour for solvent-based ink), because water is more difficult to dry than organic solvents; however, the lack of an oxidizer more than offset the difference.

Ink consumption also was lower for water-based ink compared to the baseline. On average (excluding ink usage on PE/EVA, the white substrate), 4.73 lbs of ink and 0.31 lbs of press-side solvents and additives were consumed per 6,000 ft^2 for the water-based system. This represents a 33% decrease in ink consumption and an 88% decrease in press-side solvent and additive consumption compared to the baseline.

Summary of Water-based Inks

The water-based inks studied in this CTSA were very diverse in their performance and risk results and chemical composition, but had better operating cost and resource consumption characteristics.

- Individual product lines performed equal to or better than the baseline in blocking and mottle. However, many of the results for these and other tests were worse than the baseline, highlighting the importance of carefully choosing the specific product when using a water-based ink.
- With respect to the chemical composition and worker health risks of the formulations, as indicated in Table 8.5, these inks contained from 1% to 14% VOCs and from 0% to 3.4% HAPs by weight. The relatively high VOC content in two of the product lines had significant impacts on the safety hazard ratings, and the presence of HAPs may have increased the number of chemicals with clear worker risk. Though water-based inks are often considered to be safer than solvent-based inks, the results indicate that water-based inks are not always "clean." It should be noted that the health concerns associated with cross-linkers were not addressed by this study. These chemicals, which can be added to water-based inks to improve adhesion, are thought

to cause worker health concerns but were not used in the performance demonstrations.

- The operating costs and energy consumption of water-based inks were substantially better than the baseline. Much of the difference was due to the lack of an oxidizer; for water-based inks with VOC contents above state-mandated control levels, this cost and energy advantage may be reduced substantially.

UV-cured Inks

UV-cured inks were considered a “new developing technology” for wide-web film applications when the performance demonstrations were planned and conducted in 1996. Significant changes and improvements have been made to the system and equipment since then.

Three UV-cured inks were used in this analysis. UV-cured ink #1 was tested on LDPE, UV ink #2 was tested on LDPE and PE/EVA, and UV-cured ink #3 was tested on PE/EVA; each ink was tested at one location.

Performance

As with water-based inks, some performance results were better than those of the baseline, but many were not. **Blocking** was one test in which UV-cured inks performed very well. UV-cured inks #1 and #3 both scored an average of 1.0, indicating only slight cling. UV-cured ink #2 had an average score of 2.1, which indicates more substantial cling but very little actual blocking. In contrast, the average score for the solvent baseline was 2.3. This indicates that these UV-cured inks performed well in conditions of heat and pressure.

The ratings for **gloss** were substantially lower (worse) than those for the baseline. The average score for the three coatings was 38.4, compared to the baseline value of 53.0. This is an unexpected result, since high gloss is generally thought of as a feature of UV-cured inks. The reason for this discrepancy is unknown, but it may indicate that if a high-gloss UV-cured ink is needed for a given application, the specific formulations should be chosen carefully.

The **ice water crinkle** test results were perfect on UV-cured inks #1 and #3 – no ink removal was observed. However, ink #2 was partially removed on each of the eight samples tested. This removal was observed on both LDPE and PE/EVA substrates, indicating that the effect may not be simply substrate-dependent. It may be possible that the removal is due to the formulation itself or to variables at the performance demonstration site.

Mottling associated with UV-cured inks was slightly worse than the solvent baseline, but better than that of the water-based inks. UV-cured ink #2 was equal to the baseline, with a mottle index of 205, but inks #1 and #3 were higher at 271 and 273, respectively. As for solvent- and water-based inks, the blue inks in each product line displayed more mottling.

The formulations showed a range of **trapping** values, but ultimately the average was close to that of the water-based inks. The trapping value of UV-cured ink #3 was 95%, which approached the value of the baseline. However, ink #1 had a score of only 82%. The average among the three product lines was 89%.

As for water-based inks, UV ink performance results varied considerably. Even within a product line, the performance could vary from test to test. For example, UV-cured ink #3 performed very well on the physical tests (a blocking score of 1.0, no removal with the ice water crinkle test, and a trap value of 95%). However, it received relatively poor gloss and mottle scores. The converse was true for ink #2; it had the best gloss and mottle scores of the UV inks, but had the worst blocking and ice water crinkle results.

Environmental and Health Impacts

Overall, the risks associated with UV-cured inks are marked by uncertainty. In the **occupational risk** assessment, few of the chemicals have been subjected to toxicological testing. Though the EPA Structure Activity Team (SAT) analyzed the chemicals based on their molecular structure and similarity to chemicals that have been tested, the information is considered to be less certain than that based on direct toxicological research. Testing is necessary to better understand the risks associated with this ink system. The results are based on the risks of the uncured inks, such that risk results may be overestimated if the harmful components chemically react and are integrated into the finished coating.

For UV-cured inks #1 and #3, one or two chemicals per formulation presented a clear occupational risk. This range was lower than that of the baseline. However, UV-cured ink #2 had four or five chemicals with clear risk per formulation, which was higher than the baseline range. Across the three product lines, the chemicals with clear worker risk were monomers, oligomers, colorants, and multiple function compounds. In their uncured form, some of these chemicals were reported to present clear risk through both dermal and inhalation exposure routes.

The toxicological endpoints associated with compounds in UV-cured inks are presented in Table 8.4. In contrast to the solvent-based and water-based inks, fewer types of possible human health effects associated with inhalation of the UV-cured inks were reported. It is not known, however, whether there were fewer observed effects because UV-cured inks are safer or simply because less research has been undertaken on the compounds used in this ink system.

The **safety hazard** information provided in Table 8.5 is not fully available for UV-cured chemicals, because the MSDSs for two of the product lines were generated according to guidelines other than those of the U.S. The one product line for which information was available showed a reactivity level of 1, a flammability level of 1, and it was not ignitable. These levels represent a lesser flammability and ignitability concern compared to the baseline, but the (minimal) reactivity score indicates that the ink should be stored in a dry location that is not subject to high temperatures or pressures.

The potential difference in **air releases** before and after curing can be seen by comparing the Smog-Related Emissions and Ink Content columns in Table 8.5. Particularly for UV-cured #2, substantial VOCs could be released from the uncured ink. When combined with the emissions associated with the system's high demand for electricity, the overall emissions could be significant. However, the emissions associated with the UV-cured inks were all considerably lower than those of the solvent baseline at the assumed emissions capture rate.

In contrast, the **VOC content** for the cured formulations is expected to be less than 1% by weight. The volatile matter that was found in the uncured material would be chemically transformed and incorporated into the finished product upon curing.

Overall, the UV-cured inks appeared to have fewer chemicals of concern compared to the solvent baseline, and these concerns may decrease further for cured ink. However, more research is needed into the potential health effects of the chemicals for which no direct data were available. Furthermore, though UV-cured inks #1 and #3 had fewer chemicals with clear worker risk and lower emissions than the baseline, the opposite was true for UV-cured ink #2. The risks associated with UV-cured ink formulations, therefore, may vary significantly.

Operating Costs

The cost of operating a UV-cured system was calculated to be higher than for the other two systems. The average cost was \$3.80 higher than the baseline per 6,000 ft^2. One ink, UV-cured ink #3, had lower operating costs than the baseline, but much of this is due to the fact that it was only printed on PE/EVA, and therefore white ink was not necessary.

Several factors contributed to these higher operating costs. First, the prices of UV-cured inks are approximately \$6 more for white ink and \$7 more for colored inks, per pound. Ink consumption per square inch of substrate is lower for UV inks, but if anilox rolls are not optimized for these inks, the lower consumption would not be fully realized. Another factor is that UV-cured systems also run exclusively on electricity. In contrast, solvent- and water-based inks typically fuel dryers and oxidizers with natural gas, which is less expensive. Finally, the capital cost of a UV-cured press is higher than that of a water-based ink press. Though a UV-cured press does not require hot-air dryers, the UV curing lamps are more expensive than these dryers. (The cost of a UV-cured press is expected to be similar to that of a solvent-based press, however, which also has an oxidizer system.)

Resource Conservation

UV-cured inks had both lower energy and ink consumption rates compared to the baseline. The UV-cured process consumed approximately 650,000 Btu/hour, or78,000 Btu/6,000 ft^2 at a press speed of 500 feet per minute. Both the energy costs and air releases are higher for UV than for the other two systems, though; this is because all of the energy is obtained from electricity, which is both more expensive and is produced inefficiently in comparison to on-site natural gas combustion.

The consumption rate of UV-cured inks was the lowest among the three systems. On non-PE/EVA substrates, an average of 3.47 lbs (and almost no additives) were consumed per 6,000 ft^2. When comparing this figure to the amount of ink and additives consumed by the baseline, UV-cured inks consumed six pounds less material per 6,000 ft^2.

Summary of UV-cured Inks

Like water-based inks, UV-cured inks displayed variability among the product lines.

- The performance tests had mixed results – improving upon the baseline for blocking but mostly trailing the baseline for the other tests.
- For worker risk, the UV-cured inks on average contained fewer chemicals with clear risk per formulation than the baseline. However, one ink (#2) had relatively high VOC air emission rates and more chemicals with clear risk, indicating a potential variability among the UV-cured product lines. The comparatively high number of chemicals with a clear worker health risk that only were analyzed by the SAT signals two issues. Specifically for this analysis, it indicates that there is considerable uncertainty associated with the UV risk analysis. More generally, it may indicate that compounds used in UV-cured inks are of concern but that their risks are poorly understood. These results indicate that research on these chemicals should be a priority.
- Operating costs of the UV-cured inks were higher compared to the solvent baseline, primarily because of the price of ink.

- The UV-cured inks produced better results than the baseline for resource conservation; they required less energy and considerably less ink.

8.2 QUALITATIVE SOCIAL BENEFIT-COST ASSESSMENT

Introduction to Social Benefit-Cost Assessment

Social benefit-cost analysis[a] is a tool used by policy makers to systematically evaluate the impacts to all of *society* resulting from individual decisions. A social benefit-cost analysis seeks to compare the benefits and costs of a given action, considering both the internal and external costs and benefits.[b] Such an approach is unlike business decision making, which generally only considers the internal (or private) costs and benefits of an action without taking into account any accompanying externalities.

The decision evaluated in this assessment is the choice of a flexographic ink system. Flexographic printers have a number of criteria they may use to assess which ink system technology or product line they will use. For example, a printer might consider what impact their choice of an ink system might have on operating costs, liability costs, insurance premiums, or the cost of compliance with environmental regulations. These criteria are all part of the internal decision making process; they do not include considerations that may be of importance to society as a whole.

This benefit-cost assessment considers both the impact of choosing between various ink systems and product lines on the printer (internal costs and benefits) and on other members of society (external costs and benefits), such as reductions in environmental damage and reductions in the risk of illness for the general public. Table 8.6 defines a number of terms used in this benefit-cost assessment, including externality, and public (external) costs and benefits.

[a]The term "analysis" is used here to refer to a more quantitative analysis of social benefits and costs, where a monetary value is placed on the benefits and costs to society of individual decisions. Examples of quantitative benefit-cost analyses are the regulatory impact analyses done by EPA when developing federal environmental regulations. The term "assessment" is used here to refer to a more qualitative examination of social benefits and costs. The evaluation performed in the CTSA process is more correctly termed an assessment because many of the social benefits and costs of flexographic ink technologies are identified, but not monetized.

[b]Private costs typically include any direct costs incurred by the decision maker and are generally reflected in the manufacturer's balance sheet. In contrast, public costs are incurred by parties other than the primary participants to the transaction. Economists distinguish between private and public costs because each will affect the decision maker differently. Although public costs are real costs to some members of society, they are not incurred by the decision maker, and firms do not normally take them into account when making decisions. A common example of these "externalities" is an electric utility whose emissions are reducing crop yields for the farmer operating downwind. The external costs experienced by the farmer in the form of reduced crop yields are not considered by the utility when making decisions regarding electricity production. The farmer's losses do not appear on the utility's balance sheet.

Table 8.6 Glossary of Benefit-Cost Analysis Terms

Term	Definition
Cost of Illness	A financial term referring to the liability and health care insurance costs a company must pay to protect itself against injury or disability to its workers or other affected individuals. These costs are known as illness benefits to the affected individual.
Exposed Population	The estimated number of people from the general public or a specific population group who are exposed to a chemical through wide dispersion of a chemical in the environment (e.g., DDT). A specific population group could be exposed to a chemical due to its physical proximity to a manufacturing facility (e.g., residents who live near a facility using a chemical), use of the chemical or a product containing a chemical, or through other means.
Exposed Worker Population	The estimated number of employees in an industry exposed to the chemical, process, and/or technology under consideration. This number may be based on market share data as well as estimations of the number of facilities and the number of employees in each facility associated with the chemical, process, and/or technology under consideration.
Externality	A cost or benefit that involves a third party who is not part of a market transaction; "a direct effect on another's profit or welfare arising as an incidental by-product of some other person's or firm's legitimate activity."[2] The term "externality" is a general term which can refer to either external benefits or external costs.
Human Health Benefits	Reduced health risks to workers in an industry or business as well as to the general public as a result of switching to less toxic or less hazardous chemicals, processes, and/or technologies. An example would be switching to a less volatile organic compound, lessening worker inhalation exposures as well as decreasing the formation of photochemical smog in the ambient air.
Human Health Costs	The cost of adverse human health effects associated with production, consumption, and disposal of a firm's product. An example is respiratory effects from stack emissions, which can be quantified by analyzing the resulting costs of health care and the reduction in life expectancy, as well as the lost wages as a result of being unable to work.
Indirect Medical Costs	Indirect medical costs associated with a disease or medical condition resulting from exposure to a chemical or product. Examples would be the decreased productivity of patients suffering a disability or death and the value of pain and suffering borne by the afflicted individual and/or family and friends.
Private (Internal) Benefits	The direct gain received by industry or consumers from their actions in the marketplace. One example includes the revenue a firm obtains in the sale of a good or service. Another example is the satisfaction a consumer receives from consuming a good or service.
Private (Internal) Costs	The direct costs incurred by industry or consumers in the marketplace. Examples include a firm's cost of raw materials and labor, a firm's costs of complying with environmental regulations, or the cost to a consumer of purchasing a product.
Public (External) Benefits	A positive effect on a third party who is not a part of a market transaction. For example, if an educational program results in behavioral changes which reduce the exposure of a population group to a disease, then an external benefit is experienced by those members of the group who did not participate in the educational program. For the example of nonsmokers exposed to second-hand smoke, an external benefit can be said to result when smokers are removed from situations in which they expose nonsmokers to tobacco smoke.
Public (External) Costs	A negative effect on a third party who is not part of a market transaction. For example, if a steel mill emits waste into a river which poisons the fish in a nearby fishery, the fishery experiences an external cost as a consequence of the steel production. Another example of an external cost is the effect of second-hand smoke on nonsmokers.
Social Costs	The total cost of an activity that is imposed on society. Social costs are the sum of the private costs and the public costs. Therefore, in the example of the steel mill, social costs of steel production are the sum of all private costs (e.g., raw material and labor costs) and the sum of all public costs (e.g., the costs associated with the poisoned fish).
Social Benefits	The total benefit of an activity that society receives, i.e., the sum of the private benefits and the public benefits. For example, if a new product yields pollution prevention opportunities (e.g., reduced waste in production or consumption of the product), then the total benefit to society of the new product is the sum of the private benefit (value of the product that is reflected in the marketplace) and the public benefit (benefit society receives from reduced waste).
Willingness-to-pay	Estimates used in benefits valuation are intended to encompass the full value of avoiding a health or environmental effect. For human health effects, the components of willingness-to-pay include the value of avoiding pain and suffering, impacts on the quality of life, costs of medical treatment, loss of income, and, in the case of mortality, the value of life.

Internal benefits of selecting an alternative ink system may include increased profits resulting from improved worker productivity and company image, a reduction in energy use, or reduced property and health insurance costs due to the use of less hazardous chemicals. External benefits may include improved public health from a reduction in pollutants emitted to the environment or reduced use of natural resources. Costs of the alternative ink systems may include private costs such as changes in operating expenses and public costs such as change in the price of the product charged to the consumer. Some benefits and cost are both internal and external. For example, use of an alternative ink system may result in natural resource savings. This may benefit the printer in the form of reduced water usage and a reduction in payments for water, and society as a whole in the form of reduced consumption of shared resources.

Benefit-Cost Methodology and Data Availability

The methodology for conducting a social benefit-costs assessment can be broken down into four general steps: 1) obtain information on the relative human and environmental risk, performance, cost, process safety hazards, and energy and natural resource requirements of the baseline and the alternatives; 2) construct matrices of the data collected; 3) when possible, monetize the values presented within the matrices; and 4) compare the data generated for the alternative and the baseline in order to produce an estimate of net social benefits. Section 8.1 presented the results of the first two tasks by summarizing performance, cost, energy use, risk, and safety hazard information for the baseline and alternative ink system technologies. The remainder of Section 8.2 interprets the presented data in the context of social benefit-cost assessment: the first part presents an analysis of the potential private and public costs, the second part discusses the potential private and public benefits.

Ideally, this benefit-cost chapter would quantify all of the social benefits and costs of using the different ink systems and identify the technology whose use results in the largest net social benefit. However, because of resource and data limitations and because some of the observations in the demonstrations were very site-specific, the analysis presents a qualitative description of the economic implications of the risks and other external effects associated with each technology. Benefits derived from a reduction in risk are described and discussed, but not quantified. Nonetheless, the information presented can provide useful insights when deciding between different ink systems or product lines.

The following discussions provide examples that qualitatively illustrate some of the important benefit and cost considerations. However, no overall recommendation is given. Rather, personnel in each individual facility will need to examine the information presented and identify, based on their own concerns and priorities, the best choice of ink system and product line for their facility.

Potential Private and Public Costs

It not possible to obtain comprehensive estimates of all private costs of the alternative ink systems. However, some cost components were quantifiable. For example, the cost analysis estimated the average operating costs associated with each ink system, including the material costs (ink and additive costs), labor costs for a press operator and assistant, overhead costs (rent and heat, fire and sprinkler insurance, indirect labor, repair to equipment, and administrative and sales overhead), average capital costs (base equipment, required add-ons, and installation), and energy costs (electricity and natural gas). Other cost components may contribute significantly to overall operating costs, but were not quantified because they could not be reliably estimated. These cost components include press cleaning costs, wastewater costs, sludge recycling and disposal costs, and other solid waste disposal costs.

External costs are those costs that are not included in the printer's pricing and printing decisions. These costs are commonly referred to as "externalities" and are costs that are borne by society and not by the individuals who are part of a market transaction. These costs occur in a variety of ways in the printing process. For example, if a printer uses large quantities of a non-renewable resource during the printing process, society will eventually bear the cost of depletion of this natural resource. Another example of an external cost are health effects on the population living in the communities surrounding the facility which may result from the emission of chemicals from a printing facility. The printer does not pay for any illnesses that occur outside the facility even if they are caused by the facility's air emissions. Society must bear these costs in the form of medical payments or higher insurance premiums.

Differences in the operating costs estimated in the cost analysis are summarized below.

Private Costs

Operating costs are arguably the most obvious and measurable factor influencing a business's choice of ink technologies. Lower operating costs are a direct and immediate benefit to the printer because they will directly influence the facility's bottom line. In addition, lower operating costs may allow the printer to reduce the cost per image to the consumer, thus placing the printer into a more competitive position in the market.

Table 8.7 presents the overall operating costs for all ink systems studied in the performance demonstrations, as well as a comparison between the average costs for the alternatives and the baseline. All cost data are presented for 6,000 square feet of image created at a press speed of 500 feet per minute. The data in Table 8.7 show that water-based inks (Alternative 1) had a lower average operating cost than the baseline (solvent-based inks) during the demonstrations. Water-based inks averaged a operating cost of $26.60 per 6,000 square feet of image, while solvent-based inks averaged $33.43. In addition, the range for water-based inks ($24.23 to $30.04) fell well below the range for the baseline ($31.89 to $34.06). UV-cured inks (a new developing technology for wide-web film applications) showed an average cost of $36.82, higher than both the baseline and Alternative 1. However, the lower bound of the range for this technology ($23.69) fell below the average costs for both the baseline and Alternative 1. The large range in costs for this technology ($23.69 to $51.00) is not surprising given that UV-cured inks are a new developing technology. With further technological developments, this technology is likely to become more cost competitive with the more established ink technologies.

Table 8.7 also presents a breakdown of costs used to calculate the operating cost number. Labor costs were constant across all ink systems at $5.29. Capital and energy costs changed across the systems but did not change at the product line level, with the lowest costs occurring in the water-based system at $11.41 and $0.35 respectively. Material costs were the only costs that differed by product line within an ink system. Material costs are the sum of the costs for color inks, white inks, and additives used during the performance demonstrations. With the exception of one UV product line, water-based inks had the lowest material costs.

It should be noted that these calculations are based on the costs of printing on three different substrates used during the performance demonstrations. One of the substrates, PE/EVA, does not require white ink and therefore has a lower material cost than substrates that do require white ink. Since all three systems were tested on all three substrates during the performance demonstrations, and a similar image can be created on all three substrates, the cost estimates presented in Table 8.7 are based on all results. However, actual material costs for specific systems or product lines may be higher than in the performance demonstrations if a substrate other than PE/EVA were used. Each individual printer should determine the specific costs of a system and product line, based on the substrate and facility-specific conditions, before making decisions on a system or product line.

Table 8.7 Operating Cost Breakdown per 6,000 ft^2 of Image at 500 Feet per Minute

Product Line	Material Cost	Labor Cost	Capital Cost	Energy Cost	Total Cost
Baseline: Solvent-based Ink Systems					
Solvent-based #1	$14.20	$5.29	$11.87	$0.53	$31.89
Solvent-based #2	$16.37	$5.29	$11.87	$0.53	$34.06
Average across Solvent-based Inks	*$15.29*	*$5.29*	*$11.87*	*$0.53*	*$32.98*
Alternative 1: Water-based Ink Systems					
Water-based #1	$12.99	$5.29	$11.41	$0.35	$30.04
Water-based #2	$9.73	$5.29	$11.41	$0.35	$26.78
Water-based #3	$8.31	$5.29	$11.41	$0.35	$25.36
Water-based #4	$7.18	$5.29	$11.41	$0.35	$24.23
Average across Water-based Inks	*$9.55*	*$5.29*	*$11.41*	*$0.35*	*$26.60*
New Developing Technology: UV-cured Ink Systems					
UV-cured #1	$32.81	$5.29	$11.87	$1.03	$51.00
UV-cured #2	$17.59	$5.29	$11.87	$1.03	$35.78
UV-cured #3	$5.50	$5.29	$11.87	$1.03	$23.69
Average across UV-cured Inks	*$18.63*	*$5.29*	*$11.87*	*$1.03*	*$36.82*

While lower operating costs are likely to be an important factor in a printer's choice of an ink system, it is important to note that additional costs associated with the conversion from one ink system to another may negate some or all of the cost savings discussed above. For example, substantial capital investments may be required to switch from one system to another. Examples of the costs of purchasing a new press and retrofitting a press from one system to another are presented in Table 8.8. A switch to an alternative ink system also may involve costs to retrain employees on the new printing equipment. Another influence on private costs is the press speed of the new system. In the cost chapter of the CTSA where costs were calculated at both the methodology speed and the speeds observed during the performance demonstrations, the per-image costs for labor, capital, and energy decreased at the same rate that press speed increased. Press speed is a critical cost driver, and its impacts should be assessed when an ink system switch is considered. Issues such as the level of required monitoring, along with differences in setup and cleanup, may also impact a decision among ink systems. The decision to switch from one ink technology to another is necessarily site-specific and should be made based on all costs relevant to the facility and the ink system under consideration.

Public Costs

In addition to profitability considerations, there are potential cost savings to the consumer associated with the operating cost differentials among the ink system technologies. A switch to a cheaper technology by large parts of the flexographic ink market might enable the printers to reduce the price charged to consumers.[a] However, this would only be the case if overall costs, including potential capital costs and training costs associated with switching to a different ink system, were lower than the baseline costs. Alternatively, a switch to a more expensive technology may lead to an increase in the cost to the consumer.

[a]In a competitive market, each individual firm is assumed to be a price-taker. Therefore, a benefit in terms of reduced prices to the consumer would only be possible if the number of printers switching to a cheaper technology is large enough to exert an influence on prices.

Table 8.8 Capital Costs of Changing Ink Press Technologies

	Capital Costs for New Presses			Capital Cost for Retrofitting a Press[d]		
Ink System	**Base Press Cost**	**Additional Cost**	**Total Capital Cost**	**Cost of Retrofit from Solvent System Press**	**Cost of Retrofit from Water System Press**	**Cost of Retrofit from UV System Press**
Baseline: Solvent-based Ink Systems	$2.5 million	$128,500[a]	$2.6 million		NA	NA
Alternative 1: Water-based Ink Systems	$2.5 million	$25,000[b]	$2.5 million	$60,000 - $100,000		$32,000
New Developing Technology: UV-cured Ink Systems	$2.4 million	$200,000[c]	$2.6 million	$400,000 to $500,000 when possible	$180,000 to $240,000 ($30,000 per deck)	

[a] Cost for pollution control
[b] Cost for a corona treater
[c] Cost for a corona treater, UV lamps, power supplies, and cooling unit
[d] Retrofit costs include only the additional costs of equipment. The labor, training, and downtime costs associated with a retorfit were not included because these costs are highly variable and situation specific.

Potential Private and Public Benefits

To provide the necessary information for the overall private benefit-cost comparison, a qualitative discussion of private benefits, including occupational health risks and safety hazard considerations, is presented. While these benefits could not be monetized or even quantified, they have the potential to directly affect a facility's costs and profits, and should therefore be carefully considered in the decision-making process.

Public, or external, benefits are those that do not benefit the printer directly. For example, an alternative that produces less air pollution results in both private and public benefits: the printer pays for fewer raw materials and society in general benefits from better air. The potential external benefits associated with the use of an alternative ink system include reduced health risk for the general public, reduced ecological risk, and reduced use of energy and natural resources.

Private Benefits

Performance Related Benefits

In addition to costs, performance is generally of greatest importance to any business operating in a competitive market. Performance is closely linked to the quality and appearance of the delivered product. In general, performance improvements lead to increased product revenues, and performance shortcomings lead to decreased customer satisfaction and revenues.

The CTSA assessed performance with 18 standard tests (see Chapter 4: Performance). Five of these tests were selected as summary performance tests based on their importance and quantifiability (see Section 8.1, Table 8.3). Average performance demonstration results of Alternative #1 (water-based inks) in the five summary tests were close to, but lower than, those of the baseline (solvent-based inks). The average performance results of the developing technology (UV-cured inks) were also close to, but lower than, the baseline in four of five tests. However, it is important to note that performance results of individual product lines and formulations varied considerably, so that there is substantial overlap in the performance range of the three systems. This indicates that flexographers may be able to achieve many of the performance parameters needed for their products from any of the three systems. The variation in performance by demonstration site also underscores the need to optimize ink performance (via formulation and equipment selection as well as the use of press side solvents and additives) with all systems.

Ideally, flexographers would always choose the best-performing ink system with the lowest cost. However, this CTSA indicates that there may be some cost-performance tradeoffs. Lower-cost systems and formulations may yield lower performance. Alternatively, the CTSA indicates that printers may want to consider using systems and formulations with equal or better performance and higher costs if those higher costs are accompanied by environmental benefits. Three examples of private environmental benefits in the CTSA are discussed below — reduced occupational health risk, reduced safety hazards and regulatory costs, and reduced energy use.

Occupational Health Risk

Occupational health risk refers to any health impairments that may result from the workers' exposure to hazardous chemicals. Improved occupational health may have several tangible benefits to the facility: it may lead to fewer sick days, improved worker satisfaction, improved worker productivity, and reduced insurance or compensation costs. In the context of this CTSA, occupational health risk refers to press room workers subject to dermal and inhalation exposure and prep room workers subject to dermal exposure of hazardous chemicals contained in the various ink formulations.

Table 8.4 in Section 8.1 presents a range of chemicals of concern for each product line used in the performance demonstrations. The average number of chemicals with clear SAT occupational risk associated with both Alternative 1 (1 to 4 chemicals) and the new developing technology (1 to 5 chemicals) was slightly lower th\an that of the baseline (2 to 4 chemicals). This CTSA uses the number of chemicals with occupational concern as an indication of the potential risk to press room workers. However, other factors, such as the concentration of chemicals of concern, also play an important role in assessing occupational health risks.

Lower risk to workers may have a number of monetary benefits for the printer: Reduced health risk may lead to reduced illnesses by the facility's workers, which positively influences the facility's productivity. In addition, better worker health is also likely to increase worker satisfaction (or decrease worker dissatisfaction), which can also influence worker productivity. A less hazardous working environment may also lead to lower health insurance premiums, part of which the facility may pay, and reduced workers compensation expenditures.

Safety Hazard and Regulatory Costs

Additional private benefits of reducing the number of chemicals of concern may be realized from reduced safety hazards at the facility and reduced regulatory compliance requirements. Safety hazards associated with flexographic inks include reactivity, flammability, and ignitability. Improved chemical characteristics with respect to these hazards may lead to a reduction in the insurance premiums paid by the printer, as well as a potential reduction in waste disposal and storage costs. In addition, by switching away from hazardous chemicals, a facility may be able to avoid certain regulatory and reporting requirements associated with hazardous materials. Similarly, a reduction in reporting and regulatory requirements would also produce public benefits for government, and therefore taxpayers. These benefits may stem from permit writers having to issue permits to fewer facilities or for a reduced number of chemicals, or less enforcement actions being required.

Table 8.5 in Section 8.1 summarizes safety hazard results for the three ink systems. Of the three ink systems, only solvent-based inks pose *ignitability* concerns, resulting in a greater safety hazard. Data were incomplete for reactivity and flammability characteristics of UV inks. The water-based ink technology compared favorably to the solvent-based technology in terms of *flammability* (a range of 0 to 3 compared to 3 for solvent based inks), while no difference in *reactivity* was observed between the two systems (both showed zero reactivity).

Energy Use

Energy use is another direct cost of production to the printing facility. Employing more energy efficient technologies may benefit a printer by reducing production costs as well as improving the facility's public image. With increasing environmental consciousness by the public, facilities using environmentally friendly production technologies may be able to create considerable goodwill in their communities and take advantage of advertising opportunities in addition to providing benefits to the environment and society as a whole.

The energy used by each ink system is expressed in terms of the number of British thermal units (Btu) used to produce 6,000 square feet of image. Table 8.3 in Section 8.1 shows that water-based inks and UV inks use less energy than solvent-based inks, with averages of 73,000 and 78,000 Btu, respectively, compared to 100,000 Btu used by the solvent-based ink technology. This reduced energy use may result in private and social benefits, as discussed above.

All things equal, choosing an ink technology that uses less energy during the printing process will have public benefits as well as private benefits. A reduction in energy use conserves natural resources, a benefit to society as a whole and future generations. However, it is interesting to note that the environmental impacts of energy use (and therefore public benefits) differ by energy source. For example, natural gas is relatively clean-burning compared to some sources of electricity, such as high-sulfur coal. Thus the public benefit of switching to a more energy-efficient process may be decreased if that switch entails a fuel source change from gas to coal-derived electricity.

Public Benefits

Public Health Risk

A reduction in the number of chemicals of concern not only presents private benefits to the printer but may also produce several public benefits. Society may benefit from reductions in air releases from the printing facility, which can lead to such health effects as asthma, red eyes, nausea, or headaches.[a] When present, these health effects can lead to sick days among the general public and workers living near the facility, and cause absenteeism at those workers' place of employment. A reduction in air emissions may also lead to a reduction in private and public health care costs.

Table 8.5 in Section 8.1 summarizes smog-related emissions associated with the different product lines. The table shows that at the assumed capture efficiency of 70%, solvent-based emissions of smog-related compounds from ink and energy sources are considerably higher than those from the other two systems. Solvent-based emissions ranged from 757 to 1070 g/6,000 ft^2. In contrast, water-based inks ranged from 173 to 313 g/6,000 ft^2, and UV-cured inks ranged from 187 to 523 g/6,000 ft^2. Table 8.5 also compares the product lines tested for the three ink systems in terms of VOC and HAP content. No HAP content was measured for solvent-based and UV-cured inks, whereas the HAP content for water-based inks ranged from 0 to 3.4% by weight. UV-cured inks have the lowest calculated VOC content, with 1% reported for each of the three tested product lines. The VOC content for water-based inks ranges from 1 to 14% by weight, while solvent-based inks record a range of 54 to 67%.

In addition to air emissions, there is a potential for chronic general population exposure via other pathways (e.g., drinking water, fish ingestion, etc.), or acute short-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other one-time release. Again, these potential risks are reduced when the number of chemicals of concern used at a facility is lowered.

Partially because of the chemical diversity of ink formulations within each system, potential public health benefits from a switch in ink technologies could not be quantified for this CTSA. However, some general examples can illustrate the potential economic impacts that less exposure to hazardous chemicals may have. Table 8.10 presents estimates of the economic costs of some of the illnesses or symptoms associated with exposure to flexographic printing chemicals. To the extent that flexographic printing chemicals are not the only factor contributing to the illnesses described, individual costs may overestimate the potential benefits to society from substituting alternative ink technologies for the baseline ink system. In addition, if an alternative ink system contains some of the same chemicals, the full economic benefit may not be realized.

Eye irritation, headaches, nausea, and aggravation of previously existing respiratory problems are effects associated with ozone (derived from VOCs in inks or released during energy production) or with individual compounds of possible general population risk. The economic literature provides estimates of the costs associated with eye irritation, headaches, nausea, and

[a] Asthma, red eyes, and headaches have been associated with ozone, a product of VOCs released from inks and from energy production. Lung and neurotoxic effects, which may include asthma and headaches, respectively, have been associated with compounds of possible general population risk.

asthma attacks. An analysis by Unsworth and Neumann summarizes the existing literature on the cost of illness based on estimates of how much an individual would be willing to pay to avoid certain acute effects for one symptom day.[3] These estimates are based upon a survey approach designed to elicit estimates of individual willingness-to-pay to avoid a single-day incidence of the illness. They do not reflect the lifetime costs of treating the disease.

Table 8.9 presents a summary of the low, mid-range, and high estimates of individual willingness-to-pay to avoid eye irritation, headaches, nausea, and asthma attacks. These estimates provide an indication of the benefit per affected individual that would accrue to society if switching to a substitute ink technology reduced the incidence of these health endpoints.

Table 8.9 Estimated Willingness-to-Pay to Avoid Morbidity Effects for One Symptom Day (1995 dollars)

Health Endpoint	Low	Mid-Range	High
Eye Irritation[4]	$21	$21	$46
Headache[5]	$2	$13	$67
Nausea[6]	$29	$29	$84
Asthma Attack[7]	$16	$43	$71

Ecological Risk

A potential ecological benefit of using ink formulations with fewer hazardous chemicals is reduced aquatic toxicity and less hazardous waste that needs to be disposed of in the community. Aquatic toxicity can negatively affect fish populations near the points of discharge and lead to a reduction in the variety of fish species (particularly species intolerant of environmental stressors) or a reduction in the size of fish populations. Such impacts on fish populations can impair recreational and commercial fishing opportunities. An ink system that results in the discharge of fewer chemicals of concern to aquatic populations could therefore lead to direct economic benefits in the communities surrounding the facility.

Summary of Social Benefit-Cost Assessment

The following sections present a summary of each of the three ink system technologies across the benefit and cost categories discussed in this chapter.

Solvent-based Inks

- The solvent-based ink system, on average, had lower total operating costs than UV-cured inks, but higher than water-based ink systems. This higher cost can be attributed mostly to higher material and capital costs of solvent-based technologies. In particular, average material costs for solvent-based systems (per 6,000 square feet of image) were approximately $5.00 higher than those for water-based systems.
- In the performance area, the solvent-based system on average outperformed both water-based and UV-cured systems. This system was the best with respect to gloss and trap and among the best on the other three summary performance tests.
- On average, solvent-based inks contained two to four chemicals of clear occupational risk, slightly higher than the ranges for water-based and UV-cured inks. This may indicate a higher occupational risk.
- Public health risk was evaluated through releases of smog-related compounds, VOC and HAP content, and the systemic and developmental risks to the general population.

Despite the fact that this system used oxidizers, emissions were calculated to be considerably higher than the emissions of the other systems. VOC content was, as expected, much higher than either of the two other systems. This system did not contain any HAPs. For general population risks, two chemical categories in Solvent #2 presented a possible risk.

- In terms of process safety, solvent-based inks had more concerns than the other systems, although the results for UV-cured inks were incomplete. Only solvent-based inks presented an ignitability concern and also presented a higher flammability concern than water-based inks.
- Solvent-based inks were shown to use more energy to produce the same square footage of image.

Water-based Inks

- Operating costs were lowest for the water-based ink product lines. In fact, in all cost categories, water-based ink systems had the lowest average cost. Cost savings were particularly pronounced for material costs.
- Though water-based ink formulations #2 and #4 had the best mottle scores of all product lines, overall the water-based inks did not perform as well as the solvent-based inks in the five summary performance categories. The system also was outperformed by the UV-cured inks in three categories. While this may indicate a lower quality product, it is important to note that in many cases the differences were small and may be insignificant.
- In the occupational health area, water-based inks presented a lower average number of chemicals clear or clear SAT risk per product line, indicating a better chance of reducing occupational health risks compared to the baseline.
- The amount of smog-related emissions that resulted from ink releases and energy production with the water-based system was considerably lower than that from solvent-based system, and was comparable to that from the UV-cured system. Water-based inks had a much lower VOC content than solvent-based inks, but were the only inks that contained HAPs.
- Like with solvent-based inks, printers often add VOC solvents and additives at press side to water-based inks. In substantial amounts, these materials compromise the low-VOC content of the ink and can pose clear pressroom worker risks. At one site using water-based inks (Site 3), over half of the emissions resulted from materials added at press-side.
- The safety of water-based inks was better than that of solvent-based inks. There was no indication of ignitability or reactivity. However, water-based inks had a higher flammability risk than UV-cured inks.
- As for energy expenditures, water-based inks had the lowest average energy use.

UV-cured Inks

- The UV-cured inks had the highest average operating costs. However, since it is a new developing technology for wide-web film, these costs are likely to fall as the technology develops. The biggest cost differential was the material costs, falling approximately \$8.00 per 6,000 ft^2 of image above the average costs for water-based inks. It is also worth noting that energy costs of the UV systems were considerably higher — nearly two times the cost for solvent-based inks and nearly three times the cost for water-based inks.
- The performance of the UV-cured inks was generally worse than the solvent-based baseline, though this system had better blocking resistance, and individual product lines had ice water crinkle and mottle results that were equal to the solvent-based

results. The performance results were slightly better than those of the water-based inks.

- The UV-cured inks presented the lowest chance of occupational health risk, and with respect to public health, had the lowest HAP and VOC contents. A couple SAT-analyzed compounds may present a possible general population risk, however, indicating that research on some compounds is needed.
- Safety hazard data were incomplete for UV inks. However, UV inks were the only inks that present the potential for reactivity.
- Finally, the energy used by UV-cured systems was approximately 22% less than that of the baseline, and was only slightly higher than that of the water-based inks. The air releases associated with the energy production were higher than the baseline, however, because all energy required by the UV system was derived from electricity — a more pollution-intensive energy source in comparison to natural gas.

The intent of this benefit-cost assessment is to illustrate the possible benefits and costs of switching ink systems and to give individual printers insight into the potential social benefits and costs of their current ink system. When drawing conclusions from the above discussion in this chapter, it is important to note that many of the results are based on the performance demonstrations conducted for this report. Printers may therefore find that an individual facility will not experience similar results in some or all of the benefit-cost categories. If a printer chooses to make a change in ink systems, it is important to consider the specific needs and requirements of the facility and the printer's customers.

8.3 DECISION INFORMATION SUMMARY

Introduction

This CTSA presents comparative information on the relative risk, performance, costs, and resource conservation of the three flexographic ink systems. However, it does not provide recommendations or judgments about whether or not to implement an alternative. This section may assist decision makers in choosing the most appropriate ink technology for individual circumstances. There are three parts in this section:

The **ink system comparison** summarizes the findings of Sections 8.1 and 8.2 with respect to solvent-based, water-based, and UV-cured inks. By integrating the findings of the first section and the practical benefits and costs described in the second, this comparison describes the anticipated impacts of each system based on the findings of the research in this CTSA.

After an ink system is selected, it is necessary to select specific formulations. The **chemical categories** section presents the hazard, risk, and regulatory characteristics of the groups of chemicals in this CTSA. This section may be useful for printers and ink formulators alike who wish to identify chemicals that should be avoided or that are potentially safer substitutes for harmful ingredients.

The final section, **suggestions for improvements**, summarizes the steps that can be taken by printers and ink companies to minimize the health and environmental risks of inks and considerations for selecting the best ink formulations for a facility.

Ink System Comparison

As indicated in Sections 8.1 and 8.2, the results did not identify any one ink system as a best choice for all situations. This section discusses the relative benefits and drawbacks that were found with each system.

Baseline: Solvent-based inks

The solvent-based inks were the baseline for this analysis, and they displayed solid performance characteristics and reasonable costs — two factors of primary concern to many decision makers. However, the analysis indicated that they fared poorly on other factors, such as health risks, safety hazards, regulatory costs, and energy use.

The strength of the solvent-based inks in this CTSA was performance. On average, this system produced the best performance results on four of the five tests discussed in this chapter. The results indicated that these particular inks may be the most appropriate for particularly challenging printing tasks, such when process colors must be matched precisely or when the product is intended for use in cold, wet conditions.

Health risks, safety hazards, regulatory costs, and energy use generally were negative aspects of the solvent-based inks. As indicated in Table 8.4, solvent-based inks had the highest average number of chemicals of clear worker risk per formulation (3.2). Most of the chemicals of clear risk were solvents, with some of those added at press side. The solvent-based inks had the highest VOC content— an average of 58% by weight. This directly affected the emissions rate of smog-related compounds — the average rate (914 g/6,000 ft^2) was more than three times the average rate for water-based and UV-cured systems (221 and 300 g/6,000 ft^2, respectively) at the assumed capture efficiency rate. The solvent-based inks were the only formulations that were classified as ignitable, and they also had a relatively high flammability rating of 3 (on a scale of 0-4).

Under the operating parameters assumed for this analysis, the high health risk and safety hazard indicators suggest that these solvent-based inks may result in costs to the firm in the form of more worker sick days, decreased worker satisfaction, decreased worker productivity, and increased insurance premiums. These costs would result in lower profits. Possible social impacts of solvent-based inks include increased sick days among the general public and an increase in health care costs. The flammability and ignitability of the formulations may require more effort to comply with environmental and fire regulations, thereby increasing waste disposal and storage costs. (Note, however, that solvent-based waste can be incinerated for energy recovery or distilled for reuse. Either of these practices may reduce waste disposal costs.) Finally, because oxidizers are required when using solvent-based inks, energy use was the highest for this system. The emissions associated with this energy consumption, however, were comparable to those of the other two systems, because much of the energy was derived from relatively clean-burning natural gas.

As shown in Table 8.6, the average operating cost of the solvent-based inks ($32.98 per 6,000 ft^2) was higher than that of the water-based inks ($26.60 per 6,000 ft^2), but lower than that of the UV-cured inks ($36.82 per 6,000 ft^2). Costs were increased by the use of an oxidizer and the high ink consumption rate but were moderated by the relatively low per-pound price of ink.

Alternative #1: Water-based inks

The water-based inks that were evaluated had both private advantages and disadvantages; however, the social impacts of water-based inks appear to be of less concern in comparison to the solvent baseline.

This ink system had inconsistent performance test results. Though some individual test results were better than the baseline, the average outcome of the water-based inks for each test was poorer than that of the solvent-based inks. Such a decrease in quality may either prevent printers from switching technologies or may require them to take steps to improve the quality. Two water-based product lines had better mottle results than the baseline, and in general the gloss and blocking were comparable to the solvent-based inks. Under conditions where the product is subjected to minimal physical demands, the visual characteristics of water-based inks may be similar to those of solvent-based inks. However, if the ink were to be exposed to cold or wet conditions — like those measured by the ice water crinkle test — these product lines may compare unfavorably to solvent-based inks or may require modifications.

By some measures, a switch to water-based inks may yield both private and social benefits with respect to health risks and safety hazards. In terms of safety hazards, none of the inks were ignitable or reactive. The flammability of the water-based inks ranged from 0-3, in contrast to solvent-based inks which were all rated 3. The VOC content was an average of 6% by weight, compared to the concentration of nearly 60% in solvent-based inks. For inks with low flammability and VOC content, improvements may be seen in lower insurance premiums, worker's compensation expenditures, and regulatory costs compared to those for the baseline. From a social perspective, a reduction of VOC emissions may have impacts beyond the printing facility, possibly including a reduction in cases of asthma, red eyes, and headaches. The economic benefit of avoiding additional cases of these ailments potentially could include reduced medical expenditures, increased productivity, and reduced pain and suffering.

Other health risk and safety measures indicated that the water-based inks may have been comparable to or worse than the baseline. There was an average of 3.1 compounds of clear or moderate worker health risk in the water-based inks, which was close to the 3.2 found in the solvent-based inks. Some of this risk — one compound of clear concern per formulation on average — resulted from the press-side addition of solvent and additives. Three of the four water-based ink product lines contained HAPs, while none were found in the other two systems. The variability of health risks and safety hazards of these water-based inks relative to the baseline highlights the importance of carefully scrutinizing information about particular formulations.

Benefits associated with a switch to the water-based inks in this analysis also include a decrease in energy use and costs. The system used approximately 73,000 Btu per ft^2 of image — the lowest among the ink systems and 27% less than the solvent-based inks. Private benefits of reduced energy use include reductions in the cost of energy. Social benefits include lower emissions at the sources of energy generation (i.e., electric power plants and the exhaust stack of natural gas furnaces), reduced demand for fossil fuels, and decreased strain on the capacity of the power grid.

The cost of using the water-based inks also was lower. This system was, on average, $6.40 less expensive than the baseline per 6,000 ft^2 of image. The lower cost resulting from a switch to these water-based inks has obvious benefits for a printer's profitability, and also may result in benefits to the public in the form of lower prices for printed products. When considering a switch from the baseline to a water-based ink system, additional costs for the retraining of workers would be incurred. These costs should be taken into account in the overall decision.

New Emerging Technology: UV-cured Inks

Research in this CTSA indicated that a switch to the tested UV-cured inks may present higher private costs in comparison to the baseline, because of lower performance and higher operating costs. It is worth noting that developing technologies often have higher operating costs. However, performance shortcomings indicate there is room to improve UV-cured formulations and to optimize UV equipment for wide-web film applications.

The performance results for the UV-cured inks were mixed. They performed better than the baseline on one test (blocking resistance), but produced mostly poorer results on the other tests. These results indicate that UV-cured inks may be an appropriate choice for certain film applications that require pressure and heat resistance, but that a UV system may require modifications, such as different-sized anilox rolls, to improve other performance characteristics. The performance of these inks may represent a cost to printers who are switching in that either a lower quality product is produced or that significant effort is required to improve the quality. Lower quality products affect consumers in that printed products, such as packaging, may have less realistic colors and lower durability.

These inks showed potential for greater social benefits arising from reduced health risks and safety hazards. An average of 2.4 compounds of clear or moderate occupational risk concern were found in the UV formulations, which was lower than the average for the baseline. There were no HAPs in the formulations, and based on post-curing estimates, the system had a VOC content below 1%. Safety hazard information was incomplete, but the formulations for which information was available had a reactivity level of 1, a flammability of 1 (both on 0-4 scales of increasing severity), and no ignitability. UV-cured product lines #1 and #3 were calculated to have smog-related emissions of 187 and 191 g/6,000 ft^2 of product, respectively (based on the uncured formulations). These were the lowest emission rates of all product lines in the three systems. In contrast to these relatively low figures, however, UV-cured ink #2 had VOC emissions expected to be 523 g/6,000 ft^2. The benefits of switching to a UV-cured ink, therefore, may be formulation-specific. It should be noted that many compounds used in UV-cured inks have not been subjected to toxicological studies. As a result, conclusions about the risks associated with these inks can not be as certain as conclusions based primarily on toxicological information.

The UV-cured inks consumed less energy (78,000 Btu per 6,000 ft^2) than the solvent baseline (100,000 Btu per 6,000 ft^2), but more than the water-based inks (73,000 Btu per 6,000 ft^2). As indicated in Table 8.5, the releases of smog-related compounds associated with UV-cured energy consumption were the greatest among those of the three ink systems, because electricity — the sole form of energy used by the UV system — is more pollution-intensive than natural gas. This pollution is not evident at the facility, however, because the emissions are released at the site of the power plant.

The UV-cured inks had the lowest ink consumption rate of the three systems. An average of 2.78 pounds of UV-cured ink and additives were consumed per 6,000 ft^2 of image; in contrast, the water-based system consumed 4.57 pounds of ink and additives per 6,000 ft^2, and solvent-based inks consumed 8.11 pounds per 6,000 ft^2.

With regard to costs, the UV ink system was the most expensive of the three, costing approximately \$3.80 per 6,000 ft^2 of image more than the solvent baseline and \$10 more than the water based system. Two factors drove this high cost. The per-pound ink price was the highest of the three ink systems. One reason for this is that higher-grade pigments are required in order to minimize product performance issues.[8] Another factor is that the system exclusively uses electricity, which is more expensive than natural gas. A switch to these UV-cured inks could result in a private cost to printers, and may negatively affect consumers, because the cost might be translated into higher prices for materials printed with UV-cured inks.

Summary

No ink system is inherently free of human health risks and safety hazards. There are many tradeoffs in every system. Many solvent-based inks have undergone technical reformulating in recent years to reduce the use of some of the more hazardous substances. Also, printers using solvent systems are required to use oxidizers, which can substantially reduce VOC air emissions from these inks. (Oxidizers do not, however, protect pressroom workers from the effects of solvents.) UV inks, because they are much newer, contain many more untested chemicals, and the risks of exposure to many of them are largely unknown. Water-based inks gained popularity initially in part because they were thought to be safer than solvent inks.

However, as shown by this CTSA, the relative occupational risk reductions are formulation-specific. Some water-based inks do potentially pose a lower risk than some solvent-based inks. There were fewer chemicals of clear worker health risk in some formulations, and water-based ink #2 did not contain compounds with clear developmental risks. This was not true for water-based ink #4, however; the range in the number of chemicals of clear occupational risk was slightly higher than the baseline, and this product line had a VOC content of 14% by weight. For a water-based ink, it is important to keep the VOC content as low as possible since no emission controls are used with these inks.

Another issue that emerged from the results are that press side solvents and additives can increase the risk to workers using ink. In both solvent-based and water-based inks, some solvents and additives added at press side presented a clear occupational risk. In water-based inks in particular, a third of the chemicals of clear concern were added at press side. This point highlights both the risks associated with working with press side solvents and additives and the worker health improvements that can be made by minimizing their use.

Highlights of Chemical Category Information

As noted in earlier sections of this chapter, there can be significant variation in the risks of different ink product lines, even within one ink system. The risk associated with a formulation often can be driven by just a few individual compounds. This section includes information about the hazard, risk, and regulatory information for each compound used in this CTSA, grouped by chemical category. This information may be helpful for printers who wish to identify compounds that may present issues for human health and the environment. Ink formulators may use this information to help identify chemical compounds that contribute to the overall risk of a formulation, as well as compounds that are worth considering as possible safer alternatives.

This section presents an overview and interpretation of the hazard, risk, and regulatory information. The following section — Hazard, Risk, and Regulation of CTSA Chemicals — consists of a more detailed description of each chemical category.

Hazard and risk
Hazard represents a compound's *inherent* ability to cause harm to health, that is, regardless of its concentration in an ink. Risk describes the relationship between a compound's hazard level and its potential for exposure. Because potential for exposure is a factor of the compound's concentration in the ink as well as its chemical properties, the concentration of a chemical in a formulation affects its risk. As shown in Table 8.13 in the next section, a chemical can have a low hazard score and a high risk score if the chemical is used in fairly high concentrations in an ink formulation. Thus, it is not necessarily true that pressroom workers can be safely exposed to inks even if they do not contain any highly hazardous chemicals**.**

The reverse may also be true. A chemical with a high hazard score can receive a low risk score because it has a very small concentration in the ink that was tested for the CTSA. That does not indicate, however, that the chemical is safe in all ink formulations. If the same chemical had been present in a high concentration in another formulation, it might have received a high risk score as well. Thus, it is important to pay close attention to *both* hazard and risk when this information is available.

It is also important to consider aquatic risk. Though it was assumed in this CTSA that ink would not be released to the aquatic environment, accidental releases are possible. As noted in Chapter 3 (Risk), 18 of the compounds were of high hazard concern for aquatic effects, and another 35 were of medium hazard concern. The aquatic hazard of ingredients should considered in order to minimize the impacts associated with potential discharges of ink.

Toxicological and SAT data
Ideally, a chemical's ability to cause harm in animals and humans is measured by toxicological studies. However, less than half of the compounds used in this CTSA have been subject to toxicological testing. (This situation is generally true beyond the inks that were used in this CTSA. Many hundreds of new chemicals enter the market each year, and testing has not kept up with these advances.) For CTSA chemicals with no toxicological data, EPA's Structure Activity Team (SAT) estimated toxicity based on the compound's molecular structure and its similarity to compounds that have been studied. SAT findings, although developed by experts and far better than no information, are inherently less reliable than toxicological studies, because they are not based upon actual tests of the chemical in question.

It is important, therefore, to know more about chemicals for which no toxicological data are available. As discussed in the hazard and risk section, a chemical with a low SAT risk concern may in fact be present in a particular formulation in a high enough concentration to be a worker health issue.

Exposure via dermal and inhalation routes
Flexographic workers can come into contact with all chemical compounds in ink formulations through dermal (skin) exposure, particularly if they do not consistently wear contact-barrier gloves while working with or in the immediate vicinity of inks. In contrast, workers are only subject to inhalation exposure from compounds that are volatile (have a vapor pressure at

ambient temperatures). For compounds in this CTSA that did not have a significant vapor pressure (0.001 mm Hg or greater), their inhalation risk is noted as "no exposure."

Fifteen chemicals that were tested in the CTSA presented a *clear dermal risk*, and eleven others had a possible dermal risk, documented with toxicological data. These chemicals spanned all ink systems, and a number of them are not explicitly regulated under any federal acts included in the table. SAT findings indicate that many other chemicals may also be of concern for dermal exposure. This finding indicates that flexographic workers can come into skin contact with multiple chemicals that carry significant health and safety risks. The compounds that presented clear risk as determined by toxicological data or the SAT are presented in Table 8.10.

Dermal exposure can be avoided mostly thorough implementation of a policy that requires workers to wear contact-barrier gloves while working with ink (and other chemicals), whether or not they expect to contact the ink directly. Butyl (preferred) and nitrile gloves are considered appropriate for inks. Latex gloves offer little or no protection because they degrade rapidly after being exposed to many ink chemicals.

Table 8.10 Compounds of Clear Dermal Risk

Chemical Category	Chemical	Data Source
Acrylated polyols	Dipropylene glycol diacrylate	SAT
	1,6-Hexanediol diacrylate	SAT
	Hydroxypropyl acrylate	Tox
	Trimethylolpropane triacrylate	Tox
Acrylated polymers	Glycerol propoxylate triacrylate	Tox
Alcohols	Ethanol	Tox
	Isopropanol	Tox
Alkyl acetates	Butyl acetate	Tox
Amides or nitrogenous compounds	Ammonia	Tox
	Ammonium hydroxide	Tox
	Ethanolamine	Tox
	Hydroxylamine derivative	SAT
Ethylene glycol ethers	Alcohols, C11-15-secondary, ethoxylated	SAT
	Butyl carbitol	Tox
	Ethyl carbitol	Tox
Inorganics	Barium	Tox
Organophosphorous compounds	Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	Tox
Organotitanium compounds	Isopropoxyethoxytitanium bis (acetylacetonate)	SAT
	Titanium diisopropoxide bis(2,4-pentanedionate)	SAT
	Titanium isopropoxide	SAT
Pigments — organic	C.I. Pigment Red 23	Tox
Pigments — organometallic	D&C Red No. 7	Tox

For inhalation risk, twelve chemicals showed a *clear inhalation risk* to pressroom workers based on toxicological data. SAT findings indicate that three more chemicals present a clear inhalation risk. These chemicals are listed in Table 8.11.

It is much more difficult to protect pressroom workers from inhalation exposure to ink chemicals than from dermal exposure. This is of particular concern for chemicals that have a clear or possible inhalation risk from toxicological studies, as well as those of moderate to high inhalation risk via SAT findings. Inhalation exposure can be minimized, however, by using enclosed doctor blades and providing sufficient ventilation.

Table 8.11 Compounds of Clear Inhalation Risk

Chemical Category	Chemical	Data Source
Acrylated polyols	Dipropylene glycol diacrylate	SAT
	1,6-Hexanediol diacrylate	SAT
	Hydroxypropyl acrylate	Tox
Alcohols	Ethanol	Tox
	Isobutanol	Tox
	Isopropanol	Tox
Alkyl acetates	Butyl acetate	Tox
	Ethyl acetate	Tox
Amides or nitrogenous compounds	Ammonia	Tox
	Ammonium hydroxide	Tox
	Ethanolamine	Tox
	Hydroxylamine derivative	SAT
Ethylene glycol ethers	Butyl carbitol	Tox
	Ethyl carbitol	Tox
Hydrocarbons — low molecular weight	n-Heptane	Tox

Regulatory status

Some of the compounds in this CTSA are regulated under major federal environment, health and safety acts. The following federal regulations were considered:

- Clean Air Act (CAA)
- Resource Conservation and Recovery Act (RCRA)
- Toxic Substances Control Act (TSCA)
- Clean Water Act (CWA)
- Safe Drinking Water Act (SDWA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Emergency Planning and Community Right to Know Act (EPCRA)
- Occupational Safety and Health Act (OSH Act)

Table 8.13 shows the regulation (last column) for each explicitly regulated compound. In addition, chemicals that appear to be "unregulated" in fact may be regulated due to their properties; for example, many compounds are regulated as VOCs because they match the definition (all organic compounds except those that are determined by EPA to be negligibly photochemically reactive).

Of the more than 100 chemicals studied in this CTSA, only 25% are explicitly regulated by any of the major federal environmental and health acts. Of the roughly 75 other compounds, 11 presented a clear occupational risk and another 36 presented possible occupational risk. Table 8.12 presents the compounds that posed a clear or possible occupational risk based on either toxicological data or SAT evaluations that are not explicitly listed in regulations. The large number of compounds not explicitly regulated that were of clear or possible risk concern indicates that at least for the flexographic inks studied in this analysis, significant risk may be present in a formulation despite a lack of regulatory requirements.

Table 8.12 Compounds of Clear or Possible Occupational Risk Not Explicitly Regulated[a]

Chemical	Data Source	Dermal Risk Level	Inhalation Risk Level
C.I. Pigment Red 23	Tox	Clear	n.e.
D&C Red No. 7	Tox	Clear	n.e.
Glycerol propoxylate triacrylate	Tox	Clear	n.e.
Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	Tox	Clear	n.e.
Trimethylolpropane triacrylate	Tox	Clear	n.e.
Alcohols, C11-15-secondary, ethoxylated	SAT	Clear	n.e.
Dipropylene glycol diacrylate	SAT	Clear	Clear
Hydroxylamine derivative	SAT	Clear	Clear
Isopropoxyethoxytitanium bis (acetylacetonate)	SAT	Clear	n.e.
Titanium diisopropoxide bis(2,4-pentanedionate)	SAT	Clear	n.e.
Titanium isopropoxide	SAT	Clear	n.e.
C.I. Pigment Green 7	Tox	Possible	n.e.
Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide	Tox	Possible	n.e.
Distillates (petroleum), solvent-refined light paraffinic	Tox	Possible	Possible
2-Hydroxy-2-methylpropiophenone	Tox	Possible	Possible
2-Methyl-4'-(methylthio)-2-morpholinopropiophenone	Tox	Possible	n.e.
Propylene glycol propyl ether	Tox	Possible	Possible
Acrylated epoxy polymer	SAT	Possible	n.e.
Acrylated oligoamine polymer	SAT	Possible	n.e.
Acrylated polyester polymer (#s 1 and 2)	SAT	Possible	n.e.
Acrylic acid polymer, insoluble	SAT	Possible	n.e.
Butyl acrylate-methacrylic acid-methyl methacrylate polymer	SAT	Possible	n.e.
C.I. Basic Violet 1, molybdatephosphate	SAT	Possible	n.e.
C.I. Basic Violet 1, molybdatetungstatephosphate	SAT	Possible	n.e.
C.I. Pigment Red 48, barium salt (1:1)	SAT	Possible	n.e.
C.I. Pigment Red 48, calcium salt (1:1)	SAT	Possible	n.e.
C.I. Pigment Red 52, calcium salt (1:1)	SAT	Possible	n.e.
C.I. Pigment Violet 27	SAT	Possible	n.e.

Table 8.12 Compounds of Clear or Possible Occupational Risk Not Explicitly Regulated (continued)

Chemical	Data Source	Dermal Risk Level	Inhalation Risk Level
C.I. Pigment White 7	SAT	Possible	n.e.
C.I. Pigment Yellow 14	SAT	Possible	n.e.
Distillates (petroleum), hydrotreated light	SAT	Possible	Possible
Ethoxylated tetramethyldecyndiol	SAT	Possible	n.e.
Methylenedisalicylic acid	SAT	Possible	n.e.
Nitrocellulose	SAT	Possible	n.e.
Paraffin wax	SAT	Possible	n.e.
Polyethylene glycol	SAT	Possible	n.e.
Propyl acetate	SAT	Possible	Possible
Rosin, polymerized	SAT	Possible	n.e.
Siloxanes and silicones, di-Me, 3-hydroxypropyl Me, ethers with polyethylene glycol acetate	SAT	Possible	n.e.
Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl)-, hydrolysis products with silica	SAT	Possible	n.e.
Solvent naphtha (petroleum), light aliphatic	SAT	Possible	Possible
Styrene acrylic acid polymer (#s 1 and 2)	SAT	Possible	n.e.
Styrene acrylic acid resin	SAT	Possible	n.e.
Thioxanthone derivative	SAT	Possible	n.e.
Trimethylolpropane ethoxylate triacrylate	SAT	Possible	n.e.
Trimethylolpropane propoxylate triacrylate	SAT	Possible	n.e.

n.e.: No exposure via indicated exposure route
[a] This list contains chemicals that are not explicitly listed under federal laws and regulations. Chemicals in this list may be subject to general requirements, such as those that address VOCs.

Hazard, Risk and Regulation of Individual CTSA Chemicals

This section contains hazard, risk, and regulatory information for each compound used in this CTSA. The intent of this section is to summarize the hazard and risk findings of the CTSA for the decision maker. It is intended to be a starting point in the evaluation of a chemical for use in new formulations. The data are presented in Table 8.13.

The hazard and risk information is presented separately for inhalation and dermal exposure. For both exposure routes, hazard effects can be either systemic (affecting an organ system of the body, such as the lungs) or developmental (associated with the growth and maturation of an organism). The notation used in Table 8.13 allows presentation of both systemic and developmental effects for each chemical category. The first letter that appears in each human health hazard column of the table represents the concern for systemic effects; the second represents the concern for developmental effects. For example, the second compound in the table, 1,6-hexanediol diacrylate, has "M/L" under Dermal Hazard. This indicates a moderate hazard of systemic effects, and a low hazard of developmental effects.

Table 8.13 also includes the results of the risk analysis performed in this CTSA. Risk incorporates a compound's hazard level and its potential for exposure to produce an overall risk ranking. Dermal risk levels were determined based on model assumptions of routine two-hand contact by workers in both the preparation room and the press room, and are considered high-end estimates. Inhalation risks were expected only for press room workers. Because potential for exposure depends on the compound's concentration in the ink as well as its chemical properties, the risk rating of a chemical can vary among ink formulations if its concentration is different. Table 8.13 lists the *highest* observed risk rating.

The final column of Table 8.13, Regulatory Concern, lists the regulations under which each compound is explicitly regulated. It should be noted that this is not an exhaustive list of regulatory requirements associated with each compound.

The following paragraphs summarize the hazards and risks of the chemicals in each chemical category. Though hazards and risks can vary among chemicals within a category, there are trends in exposure pathways and the magnitudes of concern that can be useful to printers and formulators who use chemicals in these categories.

Acrylated polyols

Compounds in this category were used in UV-cured inks as monomers. Of the four compounds, two (hydroxypropyl acrylate and trimethylolpropane triacrylate) have been subjected to toxicological testing. Both had a medium hazard concern for systemic effects via dermal exposure, and both were found in the inks in sufficient quantities to present clear risk via dermal exposure. Hydroxypropyl acrylate also posed a medium systemic hazard concern and clear risk via inhalation. Trimethylolpropane triacrylate did not have an appreciable vapor pressure and therefore did not pose a hazard or risk concern via inhalation. Both of these compounds had a medium aquatic hazard level, but neither had a cancer hazard rating.

The two compounds analyzed by the Structure Activity Team (SAT), dipropylene glycol diacrylate and 1,6-hexanediol diacrylate, presented medium hazard and clear risk concern by both dermal and inhalation exposure routes. The two compounds presented moderate and high hazard levels, respectively, for aquatic effects, and both were expected to have a low-moderate hazard level for carcinogenic effects.

Two compounds in this category, 1,6-hexanediol diacrylate and hydroxypropyl acrylate, are regulated under TSCA. In general, these compounds presented a clear occupational risk concern but have not been well studied.

Acrylated polymers

These six compounds were used in UV-cured inks as monomers and polymers. One compound, glycerol propoxylate triacrylate, was determined based on toxicological data to have a medium systemic dermal hazard level, and because of its concentration in the formulations, presented a clear dermal occupational risk. It also had a high aquatic hazard level.

For each of the other five compounds, the SAT found that they had a low-moderate dermal hazard level and possible dermal occupational risk. No exposure via inhalation was expected.

Of these compounds, trimethylolpropane ethoxylate triacrylate had a high aquatic hazard level, trimethylolpropane propoxylate triacrylate had a medium aquatic hazard level, and the other three — acrylated epoxy polymer, acrylated ologoamine polymer, and acrylated polyester polymer — had a low aquatic hazard level. All five of the SAT-evaluated compounds had a low-moderate cancer hazard level.

Aside from those that qualify as VOCs, none of the compounds are regulated under the federal regulations discussed in this report.

Acrylic acid polymers

Compounds in this category were used as oligomers in water-based inks. Four compounds, acrylic acid-butyl acrylate-methyl methacrylate styrene polymer, butyl acrylate-methacrylic acid-methyl methacrylate polymer, and acidic acrylic acid polymers #1 and #2 were assigned low dermal hazard levels by the SAT and possible risk ratings. The other four compounds were assigned low-moderate hazard ratings and possible occupational risk ratings via dermal exposure by the SAT. Five of the compounds — acidic acrylic acid polymers #1 and #2, styrene acrylic acid polymers #1 and #2, and styrene acrylic resin — were assigned medium aquatic hazard ratings and the other three compounds were assigned low ratings. None of the compounds were known to present a cancer hazard, nor are they explicitly regulated under the federal regulations discussed in this report.

Alcohols

Alcohols were used in all three ink systems as solvents. All except tetramethyldecyndiol have received toxicological testing and had human health hazard and occupational risk concern via both dermal and inhalation exposure. Most compounds presented only low or medium hazard concern, but because of their typically high concentrations, their occupational risk levels were higher. Three had a clear inhalation risk (ethanol, isobutanol, and isopropanol), and two had a clear dermal risk (ethanol and isopropanol). Tetramethyldecyndiol, as determined by the SAT, had a medium aquatic hazard level; the other compounds had a low aquatic hazard level.

Ethanol has been assigned by the International Agency for Research on Cancer (IARC) as a Group 1 compound, indicating that it is carcinogenic to humans. Isopropanol has been assigned as an IARC Group 3 compound, indicating that its characteristics with respect to cancer are not classifiable. Propanol has been assigned as an EPA Group C compound, indicating that it is a possible human carcinogen.

Three compounds in this category have OSHA Personal Exposure Limits (PELs); for ethanol, it is 1000 ppm, for isobutanol, it is 100 ppm, and for isopropanol, it is 400 ppm. Three compounds are regulated by TSCA, and RCRA, CERCLA, and EPCRA regulations apply to one compound.

Alkyl acetates

The three compounds in this category were used as solvents in solvent-based inks. Butyl acetate and ethyl acetate have been subjected to toxicological testing. Like alcohols, they had fairly low human health hazard levels, but their relatively high concentrations in these inks caused both compounds to have a clear occupational risk concern via inhalation exposure. Butyl acetate also presented a clear occupational risk via dermal exposure. Propyl acetate, which was studied by the SAT, was given low-moderate hazard and possible risk concern levels via both exposure pathways. All three compounds presented a medium aquatic hazard, and none were known to pose a cancer hazard.

Butyl and ethyl acetate are regulated under CERCLA, TSCA, and have OSHA PELs of 150 ppm and 400 ppm, respectively. In addition, butyl acetate is regulated under CWA and ethyl acetate is regulated under RCRA.

Amides or nitrogenous compounds

This is a broad category, incorporating compounds serving a variety of functions in all ink systems. Four compounds — ammonia, ammonium hydroxide, ethanolamine, and hydroxylamine derivative — presented a clear occupational risk concern via both dermal and inhalation exposure routes. Ethanolamine also presented a high human health hazard for developmental effects by both exposure routes. In contrast, the other three compounds presented low hazard and occupational risk levels. Two compounds — hydrogenated tallow amides and ammonia — presented a high aquatic hazard, and three others — ammonium hydroxide, ethanolamine, and hydroxylamine derivative — presented a medium aquatic hazard concern. None of the compounds were known to present a cancer hazard.

Ammonia and ammonium hydroxide are subject to CWA, CERCLA, and EPCRA requirements, and ammonia is also subject to CAA, SARA, TSCA and has an OSHA PEL of 50 ppm. Ethanolamine has an OSHA PEL of 3 ppm, and urea is regulated under TSCA.

Aromatic esters

This category was comprised of two compounds found in UV-cured inks. Dicyclohexyl phthalate was an additive (a plasticizer) and ethyl 4-dimethylaminobenzoate was a photoinitiator. Dicyclohexyl phthalate has been subjected to toxicological testing and presented a low concern for both human health hazard and occupational risk, but a high concern for aquatic hazard. The other, ethyl 4-dimethylaminobenzoate, was analyzed by the SAT and was given a low-moderate human health hazard level and a possible risk level for both dermal and inhalation pathways, a medium aquatic hazard level, and a low-moderate cancer hazard level. Dicyclohexyl phthalate is regulated under CWA, CERCLA, and TSCA.

Aromatic ketones

The seven compounds in this category were used as photoinitators in the UV-cured inks of this CTSA. One compound, 2-hydroxy-2-methylpropiophenone, presented a moderate hazard and possible risk via both inhalation and dermal exposure based on toxicological data. For the other compounds, the concern was limited to dermal exposure. 2-methyl-4'-(methylthio)-2-morpholinopropiophenone presented moderate hazard concern and possible risk concern via dermal exposure based on toxicological data. The other compounds had low human health hazard and low or possible dermal occupational risk concern. 2-Isopropylthioxanthone, 4-isopropylthioxanthone and thioxanthone derivative were found by the SAT to have a high aquatic hazard concern; three others had a medium aquatic hazard concern. None of the compounds were known to present a cancer hazard or are explicitly regulated under the federal regulations discussed in this document.

Ethylene glycol ethers

These compounds were used as solvents in water-based inks. Two compounds — butyl carbitol and ethyl carbitol — present clear occupational risk concern via both dermal and inhalation exposure based on toxicological data. The three other compounds were analyzed by the SAT. Ethoxylated C11-C15 secondary alcohols was given a moderate hazard level and clear occupational risk level via dermal exposure, and no inhalation exposure was expected. The other two compounds, ethyoxylated tetramethyldecyndiol and polyethylene glycol, were given moderate hazard levels and possible dermal occupational risk levels. Ethoxylated C11-C15 secondary alcohols presented a medium aquatic hazard; all others had a low aquatic hazard level. None of the compounds were known to present a cancer hazard.

Both butyl and ethyl carbitol are regulated under CAA, CERCLA, EPCRA, and TSCA.

Hydrocarbons — high molecular weight

The four compounds included in this category were used as additives in solvent- and water-based inks. Based on toxicological data, solvent-refined light paraffinic distillates and paraffin wax were found to pose a possible occupational risk level by dermal exposure, and solvent-refined light paraffinic distillates also posed a possible occupational risk by inhalation exposure. Hydrotreated light distillates were found by the SAT to present a possible occupational risk by both dermal and inhalation exposure. Hydrotreated light distillates and mineral oil both presented high aquatic hazard, and hydrotreated light distillates and solvent-refined light paraffinic distillates have shown evidence of carcinogenicity in animals (but have not been evaluated formally by IARC or EPA).

Mineral oil has been assigned an OSHA PEL of 5 mg/m^3.

Hydrocarbons — low molecular weight

The three compounds included in this category were found in solvent- and water-based inks and performed different functions. Heptane, though it posed only a low hazard concern for both dermal and inhalation exposure based on toxicological data, presented a clear occupational risk concern for inhalation, in part because of its greater concentration in some formulations. In contrast, styrene posed a high concern for developmental effects via inhalation based on toxicological data, but its relatively low concentration resulted in just a rating of possible risk concern for inhalation effects. Light aliphatic solvent naphtha was given a low-moderate hazard and possible occupational risk rating for both dermal and inhalation exposure by the SAT. Heptane and styrene presented a high aquatic hazard concern, and light aliphatic solvent naphtha presented a medium aquatic hazard. There is evidence in animals that styrene may be carcinogenic, but it has not been evaluated by IARC or EPA.

Two compounds are regulated under multiple federal acts. Heptane is regulated under TSCA and has an OSHA PEL of 500 ppm. Styrene is regulated under CAA, CWA, SDWA, CERCLA, SARA, EPCRA, TSCA, and has an OSHA PEL of 100 ppm.

Inorganics

The compounds in this category perform a diverse set of functions in solvent- and water-based inks and have all been subjected to toxicological testing. One of the compounds, barium, is of particular concern. It had a high hazard concern for developmental effects via dermal exposure, and had clear occupational dermal risk. The other two compounds, kaolin and silica, had low human health hazard and occupational risk concern ratings, and all three compounds had low aquatic hazard ratings. Two compounds may present a cancer hazard: silica in its crystalline form is classified by IARC as a Group 1 compound (carcinogenic to humans), and amorphous silica is classified as a Group 3 compound (not classifiable as to its carcinogenicity in humans); and kaolin has been reported to cause cancer in animals but has not been evaluated formally.

Barium and kaolin have OSHA PELs of 0.5 mg/m^3 and 15 mg/m^3 (total dust), respectively. Barium is also regulated under RCRA, SDWA, SARA, and EPCRA.

Olefin polymers

The two compounds in this category, polyethylene and polytetrafluoroethylene, were used as additives (waxes) in solvent-based and UV-cured inks. Polytetrafluoroethylene presented low dermal hazard and risk concern based on toxicological information. Polyethylene was determined through SAT evaluation to have a low hazard and possible dermal risk concern. Both have been studied by IARC for cancer hazards and found to be Group 3 compounds (not classifiable). No inhalation exposure was expected from these compounds, both presented a low aquatic hazard, and neither is explicitly regulated under the federal acts discussed in this report.

Organic acids or salts

These compounds performed a variety of functions as additives in solvent- and water-based inks. Citric acid, the only compound for which toxicological data were available, presented low concern for human health hazard and occupational risk via dermal exposure. The other two compounds, dioctyl sulfosuccinate sodium salt and methylenedisalicylic acid, were analyzed by the SAT and found to present low-moderate hazard and possible risk concern via dermal exposure. All three presented a moderate aquatic hazard. None of the compounds were expected to result in inhalation exposure, and none are explicitly regulated under the federal acts discussed in the CTSA.

Organophosphorous compounds

The three compounds included in this category were used in solvent-based and UV-cured inks as either plasticizers or initiators and have been subjected to toxicological testing. One compound, bis(2,6-dimethoxybenzoyl)(2,4,4-trimethylpentyl) phosphine oxide, had a moderate dermal hazard and clear occupational dermal risk concern. The other two, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide and 2-ethylhexyl diphenyl phosphate, presented low and low-moderate dermal hazard concern, respectively, and possible occupational risk by dermal exposure. 2-Ethylhexyl diphenyl phosphate presented a high aquatic hazard and the other two presented a medium aquatic hazard. None of the compounds were expected to result in inhalation exposure. One compound, 2-ethylhexyl diphenyl phosphate, is regulated under TSCA.

Organotitanium compounds

These three compounds were used in solvent-based inks as additives (adhesion promoters). Each was studied by the SAT and found to have medium human health hazard and clear occupational risk levels for dermal exposure. Isopropoxyethoxytitanium bis (acetylacetonate) and titanium diisopropoxide bis (2,4-pentanedionate) presented a medium aquatic hazard concern. Isopropoxyethoxytitanium bis (acetylacetonate) also presented a low-moderate cancer hazard concern. Inhalation exposure was not expected from any of the compounds. None of the compounds are explicitly regulated under the federal regulations discussed in this document.

Pigments — inorganic

This category was comprised of two chemicals and was seen in all three ink systems. C.I. Pigment White 6 had a low dermal hazard rating but a possible dermal risk rating based on toxicological data. C.I. Pigment White 7 was analyzed by the SAT and found to have a low-moderate hazard and possible risk ranking for dermal exposure. Both compounds had a low aquatic hazard rating, but C.I. Pigment White 6 has displayed evidence of carcinogenicity in animals. Inhalation exposure was not expected from either of the compounds. C.I. Pigment White 6 has an OSHA PEL of 15 mg/m^3 (total dust).

Pigments — organic

This category was comprised of six compounds and were seen in all three ink systems. Toxicological data were available for only one compound, C.I. Pigment Red 23, which was found to have clear dermal concern. The other compounds in this category were analyzed by the SAT and found to have low or low-moderate human health hazard and low or possible occupational risk levels. C.I. Pigment Blue 61 presented a medium aquatic hazard; the others had a low aquatic hazard concern. C.I. Pigment Yellow 14 was found to present a low-moderate cancer hazard concern. Inhalation exposure was not expected for any of these compounds, and none of the compounds are explicitly regulated under the federal regulations discussed in this document.

Pigments — organometallic

Nine organometallic pigments were used in all three ink systems. One compound, D&C Red No. 7, presented medium dermal systemic hazard and clear dermal risk based on toxicological data. One other compound subjected to toxicological testing, C.I. Pigment Green 7, presented a possible dermal risk level. Most of the other inks, as determined by the SAT, presented low-moderate dermal hazard and possible dermal occupational risk concern. Most of the compounds had a medium or high aquatic hazard level, and all of the SAT-analyzed compounds presented a low-moderate cancer hazard. Inhalation exposure was not expected for any of these compounds, and none of the compounds are explicitly regulated under the federal regulations discussed in this document.

Polyol derivatives

These compounds were used in solvent-based and UV-cured inks as resins. For nitrocellulose, the SAT assigned a low-moderate human health hazard and possible occupational risk level by dermal exposure and a low aquatic hazard level. Polyol derivative A had low human health hazard and occupational risk ratings via dermal exposure and a low aquatic hazard rating. Inhalation exposure was not expected for either compound, and neither of the compounds is explicitly regulated under the federal regulations discussed in this document.

Propylene glycol ethers

These compounds were used as solvents in solvent- and water-based inks, and have all been subjected to toxicological testing. Propylene glycol propyl ether, based on toxicological data, presented a moderate systemic human health hazard concern via both dermal and inhalation exposure routes, and had possible dermal and inhalation occupational risk concern. The other two compounds, dipropylene glycol methyl ether and propylene glycol methyl ether, presented a low hazard concern and a low occupational risk for both exposure pathways at the concentrations observed in the inks used in this CTSA. All three compounds had a low aquatic hazard, and none were known to present a cancer hazard.

Two compounds, dipropylene glycol methyl ether and propylene glycol methyl ether, are regulated under TSCA. In addition, dipropylene glycol methyl ether has an OSHA PEL of 100 ppm.

Resins

Resins were found in solvent- and water-based inks. One compound, polymerized rosin, presented a low-moderate human health hazard and a possible risk concern as determined by the SAT. All other compounds in this category presented low human health hazard and low occupational risk for dermal exposure. One chemical — resin acids, hydrogenated, methyl esters — had a high aquatic hazard rating, and acrylic resin had a medium aquatic hazard rating. Acrylic resin also may pose a cancer hazard based on evidence of carcinogenicity in animals. Inhalation exposure was not expected for any of these compounds, and none of the compounds are explicitly regulated under the federal regulations discussed in this document.

Siloxanes

These compounds are used in all three systems as additives (defoamers and wetting agents). Silicone oil, as determined through toxicological data, was anticipated to have moderate developmental hazard concern via dermal exposure, and possible dermal risk. The other two compounds, 1,1,1-trimethyl-N-(trimethylsilyl)-silanamine hydrolysis products with silica and dimethyl 3-hydroxypropyl methyl siloxanes and silicones, ethers with polyethylene glycol acetate, were analyzed by the SAT and determined to have a low-moderate human health hazard and a possible dermal risk concern. All of the compounds had a low aquatic hazard rating, and none were known to present a cancer hazard. No inhalation exposure is anticipated for any of these compounds. Silicone oil is regulated under TSCA.

Table 8.13 Summary of Hazard and Risk Data by Chemical Category

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Acrylated polyols									
UV	Dipropylene glycol diacrylate 57472-68-1	SAT	M	low-moderate SAT concern	M/M	M/M	clear	clear	
	1,6-Hexanediol diacrylate 13048-33-4	SAT	H	low-moderate SAT concern	M/L	M/L	clear	clear	TSCA
	Hydroxypropyl acrylate 25584-83-2	Tox	M		M/NA	M/NA	clear	clear	TSCA
	Trimethylolpropane triacrylate 15625-89-5	Tox	M		M/L		clear	n.e.	
Acrylated polymers									
UV	Acrylated epoxy polymer[e] CAS: NA	SAT	L	low-moderate SAT concern	L-M/L-M		possible	n.e.	
	Acrylated oligoamine polymer[e] CAS: NA	SAT	L	low-moderate SAT concern	L-M/L-M		possible	n.e.	
	Acrylated polyester polymer (#'s 1 and 2)[e] CAS: NA	SAT	L	low-moderate SAT concern	L-M/L-M		possible	n.e.	
	Glycerol propoxylate triacrylate 52408-84-1	Tox	H		M/NA		clear	n.e.	
	Trimethylolpropane ethoxylate triacrylate 28961-43-5	SAT	H	low-moderate SAT concern	L-M/NA		possible	n.e.	
	Trimethylolpropane propoxylate triacrylate 53879-54-2	SAT	M	low-moderate SAT concern	L-M/L-M		possible	n.e.	

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Acrylic acid polymers									
Water	Acrylic acid-butyl acrylate-methyl methacrylate styrene polymer 27306-39-4	SAT	L		L/L		low	n.e.	
	Acrylic acid polymer, acidic (#'s 1 and 2)[e] CAS: NA	SAT	M		L/L		low	n.e.	
	Acrylic acid polymer, insoluble[e] CAS: NA	SAT	L		L-M/L-M		possible	n.e.	
	Butyl acrylate-methacrylic acid-methyl methacrylate polymer 25035-69-2	SAT	L		L/L		low	n.e.	
	Styrene acrylic acid polymer (#'s 1 and 2)[e] CAS: NA	SAT	M		L-M/L-M		possible	n.e.	
	Styrene acrylic acid resin[e] CAS: NA	SAT	M		L-M/L-M		possible	n.e.	
Alcohols									
Solvent Water UV	Ethanol 64-17-5	Tox	L	IA RC Group 1[f]	H/M	L	clear	clear	OSHA PEL
	Isobutanol 78-83-1	Tox	L		L-M/NA	M	possible	clear	RCRA, CERCLA, TSCA, OSHA PEL
	Isopropanol 67-63-0	Tox	L	IARC Group 3[g]	L-M/H	M/L	clear	clear	EPCRA, TSCA, OSHA PEL
	Propanol 71-23-8	Tox	L	EPA Group C[h]	M/L	M/L	possible	possible	TSCA
	Tetramethyldecyndiol 126-86-3	SAT	M		L/NA		low	n.e.	
Alkyl acetates									
Solvent	Butyl acetate 123-86-4	Tox	M		L/L	L/L	clear	clear	CERCLA, CWA, TSCA, OSHA PEL
	Ethyl acetate 141-78-6	Tox	M		L/NA	M/NA	possible	clear	RCRA, CERCLA, TSCA, OSHA PEL
	Propyl acetate 109-60-4	SAT	M		L-M/L-M	L-M/L-M	possible	possible	

[a] The first letter(s) represents systemic concern, the second represents developmental concerns.
L= Low; M = Medium; H = High; NA = No data or information are available; n.e. = No Exposure
[b] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001 mmHg).
[c] Dermal occupational risk is applicable for press and prep room workers; inhalation risk is applicable for press room workers.
[d] The information in this column currently is being reviewed, and this column only lists federal regulations in which the chemical is listed explicitly. Other regulations may apply to each chemical.
[e] Some structural information is given for these chemicals. For polymers, the submitter has supplied the number average molecular weight and degree of functionality. The physical property data are estimated from this information.
[f] An IARC Group 1 compound is carcinogenic to humans.
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[h] An EPA Group C compound is a possible human carcinogen.
[i] Actual chemical name is confidential business information.

Table 8.13 Summary of Hazard and Risk Data by Chemical Category (continued)

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Amides or nitrogenous compounds									
Solvent Water UV	Amides, tallow, hydrogenated 61790-31-6	SAT	H		L/L		low	n.e.	
	Ammonia 7664-41-7	Tox	H		M/NA	L/NA	clear	clear	CAA, CWA, CERCLA, SARA, EPCRA, TSCA, OSHA PEL
	Ammonium hydroxide 1336-21-6	Tox	M		L/NA	L/NA	clear	clear	CWA, CERCLA, EPCRA
	Erucamide 112-84-5	SAT	L		L/NA		low	n.e.	
	Ethanolamine 141-43-5	Tox	M		L/H	L/H	clear	clear	OSHA PEL
	Hydroxylamine derivative CAS: NA	SAT	M		M/M	M/M	clear	clear	
	Urea 57-13-6	Tox	L		L/L	L/L	low	low	TSCA
Aromatic esters									
UV	Dicyclohexyl phthalate 84-61-7	Tox	H		L/L	L/L	low	n.e.	CWA, CERCLA, TSCA
	Ethyl 4-dimethylaminobenzoate 10287-53-5	SAT	M	low-moderate SAT concern	L-M/L-M	L-M/L-M	possible	possible	
Aromatic ketones									
UV	2-Benzyl-2-(dimethylamino)-4'-morpholinobutyrophenone 119313-12-1	Tox	M		L/NA		low	n.e.	
	1-Hydroxycyclohexyl phenyl ketone 947-19-3	SAT	M		L/L		low	n.e.	
	2-Hydroxy-2-methylpropiophenone 7473-98-5	Tox	L		M/NA	M/NA	possible	possible	
	2-Isopropylthioxanthone 5495-84-1	SAT	H		L/L		low	n.e.	
	4-Isopropylthioxanthone 83846-86-0	SAT	H		L/L		low	n.e.	
	2-Methyl-4'-(methylthio)-2-morpholinopropiophenone 71868-10-5	Tox	M		M/M		possible	n.e.	
	Thioxanthone derivative[e] CAS: NA	SAT	H		L-M/NA		possible	n.e.	

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Ethylene glycol ethers									
Water	Alcohols, C11-15-secondary, ethoxylated 68131-40-8	SAT	M		M/M	M/M	clear	n.e.	
	Butyl carbitol 112-34-5	Tox	L		L/L	M/L	clear	clear	CAA, CERCLA, EPCRA, TSCA
	Ethoxylated tetramethyldecyndiol 9014-85-1	SAT	L		L-M/NA	L-M/NA	possible	n.e.	
	Ethyl carbitol 111-90-0	Tox	L		M-H/L	M-H/L	clear	clear	CAA, CERCLA, EPCRA, TSCA
	Polyethylene glycol 25322-68-3	Tox	L		L/NA	L/NA	possible	n.e.	
Hydrocarbons - high molecular weight									
Solvent Water	Distillates (petroleum), hydrotreated light 64742-47-8	SAT	H	animal evidence	M/M	M/M	possible	possible	
	Distillates (petroleum), solvent-refined light paraffinic 64741-89-5	Tox	L	animal evidence	L/NA	L/NA	possible	possible	
	Mineral oil 8012-95-1	Tox	H		L/L	L/L	low	low	OSHA PEL
	Paraffin wax 8002-74-2	SAT	L		NA/NA		possible	n.e.	
Hydrocarbons - low molecular weight									
Solvent Water	n-Heptane 142-82-5	Tox	H		L/NA	L/NA	low	clear	TSCA, OSHA PEL
	Solvent naphtha (petroleum), light aliphatic 64742-89-8	SAT	M		L-M/NA	L-M/NA	possible	possible	
	Styrene 100-42-5	Tox	H	animal evidence	M-L/L	M/H	low	possible	CAA, CWA, SDWA, CERCLA, SARA, EPCRA, TSCA, OSHA PEL

[a] The first letter(s) represents systemic concern, the second represents developmental concerns.
L= Low; M = Medium; H = High; NA = No data or information are available; n.e. = No Exposure
[b] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001 mmHg).
[c] Dermal occupational risk is applicable for press and prep room workers; inhalation risk is applicable for press room workers.
[d] The information in this column currently is being reviewed, and this column only lists federal regulations in which the chemical is listed explicitly. Other regulations may apply to each chemical.
[e] Some structural information is given for these chemicals. For polymers, the submitter has supplied the number average molecular weight and degree of functionality. The physical property data are estimated from this information.
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[g] An IARC Group 3 compound is not classifiable as to its carcinogenicity to humans.
[h] An EPA Group C compound is a possible human carcinogen.
[i] Actual chemical name is confidential business information.

Table 8.13 Summary of Hazard and Risk Data by Chemical Category (continued)

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Inorganics									
Solvent Water	Barium 7440-39-3	Tox	L		M/H		clear	n.e.	RCRA, SDWA, SARA, EPCRA, OSHA PEL
	Kaolin 1332-58-7	Tox	L	animal evidence	L/L		low	n.e.	OSHA PEL
	Silica 7631-86-9	Tox	L	crystalline: IARC Group 1 amorphous: IARC Group 3	NA/NA		low	n.e.	
Olefin polymers									
Solvent UV	Polyethylene 9002-88-4	SAT	L	IARC Group 3	L/L		low	n.e.	
	Polytetrafluoroethylene 9002-84-0	Tox	L	IARC Group 3	L/NA		low	n.e.	
Organic acids or salts									
Solvent Water	Citric acid 77-92-9	Tox	M		L/L		low	n.e.	
	Dioctyl sulfosuccinate, sodium salt 577-11-7	SAT	M		L-M/L-M			n.e.	
	Methylenedisalicylic acid 27496-82-8	SAT	M		L-M/L-M		possible	n.e.	
Organophosphorus compounds									
Solvent UV	Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 75980-60-8	Tox	M		L/NA		possible	n.e.	
	2-Ethylhexyl diphenyl phosphate 1241-94-7	Tox	H		L-M/M		possible	n.e.	TSCA
	Phosphine oxide, bis(2,6-dimethoxy-benzoyl) (2,4,4-trimethylpentyl)- 145052-34-2	Tox	M		M/NA		clear	n.e.	
Organotitanium compounds									
Solvent	Isopropoxyethoxytitanium bis (acetylacetonate) 68586-02-7	SAT	M	low-moderate SAT concern	M/M	M/M	clear	n.e.	
	Titanium diisopropoxide bis(2,4-pentanedionate) 17927-72-9	SAT	M		M/M	M/M	clear	n.e.	
	Titanium isopropoxide 546-68-9	SAT	L		M/M	M/M	clear	n.e.	

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Pigments - inorganic									
Solvent Water UV	C.I. Pigment White 6 13463-67-7	Tox	L	animal evidence	L/NA		possible	n.e.	OSHA PEL
	C.I. Pigment White 7 1314-98-3	SAT	L		L-M/L-M		possible	n.e.	
Pigments - organic									
Solvent Water UV	C.I. Pigment Blue 61 1324-76-1	SAT	M		L/L		low	n.e.	
	C.I. Pigment Red 23 6471-49-4	Tox	L		L/NA		clear	n.e.	
	C.I. Pigment Red 269 67990-05-0	SAT	L		L/L		low	n.e.	
	C.I. Pigment Violet 23 6358-30-1	SAT	L		L/L		low	n.e.	
	C.I. Pigment Yellow 14 5468-75-7	SAT	L	low-moderate SAT concern	L-M/L-M		possible	n.e.	
	C.I. Pigment Yellow 74 6358-31-2	SAT	L		L/L		low	n.e.	
Pigments - organometallic									
Solvent Water UV	C.I. Basic Violet 1,molybdatephosphate 67989-22-4	SAT	H	low-moderate SAT concern	L-M/L-M		possible	n.e.	
	C.I. Basic Violet 1, molybdate-tungstatephosphate 1325-82-2	SAT	H	low-moderate SAT concern	L-M/L-M		possible	n.e.	
	C.I. Pigment Blue 15 147-14-8	Tox	L		L/NA		low	n.e.	
	C.I. Pigment Green 7 1328-53-6	Tox	L		L/NA		possible	n.e.	
	C.I. Pigment Red 48, barium salt (1:1) 7585-41-3	SAT	M	low-moderate SAT concern	L-M/NA		possible	n.e.	
	C.I. Pigment Red 48, calcium salt (1:1) 7023-61-2	SAT	M	low-moderate SAT concern	L-M/NA		possible	n.e.	
	C.I. Pigment Red 52, calcium salt (1:1) 17852-99-2	SAT	M	low-moderate SAT concern	L-M/L-M		possible	n.e.	
	C.I. Pigment Violet 27 12237-62-6	SAT	H	low-moderate SAT concern	L-M/L-M		possible	n.e.	
	D&C Red No. 7 5281-04-9	Tox	M		M/L		clear	n.e.	

[a] The first letter(s) represents systemic concern, the second represents developmental concerns.
L= Low; M = Medium; H = High; NA = No data or information are available; n.e. = No Exposure
[b] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001 mmHg).
[c] Dermal occupational risk is applicable for press and prep room workers; inhalation risk is applicable for press room workers.
[d] The information in this column currently is being reviewed, and this column only lists federal regulations in which the chemical is listed explicitly. Other regulations may apply to each chemical.
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[i] Actual chemical name is confidential business information.

Table 8.13 Summary of Hazard and Risk Data by Chemical Category (continued)

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Polyol derivatives									
Solvent UV	Nitrocellulose 9004-70-0	SAT	L		NA/NA		possible	n.e.	
	Polyol derivative A[i] CAS: NA	SAT	L		L/L		low	n.e.	
Propylene glycol ethers									
Solvent Water	Dipropylene glycol methyl ether 34590-94-8	Tox	L		L/NA	L/NA	low	low	TSCA, OSHA PEL
	Propylene glycol methyl ether 107-98-2	Tox	L		L/L	L/L			TSCA
	Propylene glycol propyl ether 1569-01-3	Tox	L		M/L	M/L	possible	possible	
Resins									
Solvent Water	Fatty acid, dimer-based polyamide[e] CAS: NA	SAT	L		L/L		low	n.e.	
	Fatty acids, C18-unsatd., dimers, polymers with ethylenediamine, hexamethylenediamine, and propionic acid 67989-30-4	SAT	L		L/L		low	n.e.	
	Resin acids, hydrogenated, methyl esters 8050-15-5	SAT	H		L/L		low	n.e.	
	Resin, acrylic[e] CAS: NA	Tox	M	animal evidence	L/L		low	n.e.	
	Resin, miscellaneous[e] CAS: NA		NA					n.e.	
	Rosin, fumarated, polymer with diethylene glycol and pentaerythritol 68152-50-1	SAT	L		L/L		low	n.e.	
	Rosin, fumarated, polymer with pentaerythritol, 2-propenoic acid, ethenylbenzene, and (1-methylethylenyl)benzene[e] CAS: NA	SAT	L		NA/NA		low	n.e.	
	Rosin, polymerized 65997-05-9	SAT	L		L/L		possible	n.e.	

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Siloxanes									
Solvent Water UV	Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl) -, hydrolysis products with silica 68909-20-6	SAT	L		L/L		possible	n.e.	
	Silicone oil 63148-62-9	Tox	L		L/M		possible	n.e.	TSCA
	Siloxanes and silicones, di-methyl, 3-hydroxypropyl methyl, ethers with polyethylene glycol acetate 70914-12-4	SAT	L		NA/NA		possible	n.e.	

[a] The first letter(s) represents systemic concern, the second represents developmental concerns.
L= Low; M = Medium; H = High; NA = No data or information are available; n.e. = No Exposure
[b] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001 mmHg).
[c] Dermal occupational risk is applicable for press and prep room workers; inhalation risk is applicable for press room workers.
[d] The information in this column currently is being reviewed, and this column only lists federal regulations in which the chemical is listed explicitly. Other regulations may apply to each chemical.
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[h] An EPA Group C compound is a possible human carcinogen.
[i] Actual chemical name is confidential business information.

Suggestions for Evaluating and Improving Flexographic Inks

As this CTSA shows, several factors are involved in the selection of a flexographic ink. Because flexographic printing facilities are different, the criteria for identifying the best ink for each facility inevitably will vary. Therefore, the ultimate decision will have to be made based on considerations as they apply to the specific facility.

Likewise, ink formulators will have different considerations. In the process of improving the performance of inks, formulators will encounter the opportunity to substitute ink components that pose health concerns with those that are safer for press workers and the environment.

The following sections describe some of the steps that can help printers in identifying, and formulators in creating, safer flexographic inks. They range from steps that relate directly to information and ideas contained in the CTSA to those that will require processes outside of those considered in this analysis.

Printers

The selection of a specific ink is a complex process that is highly dependent on facility-specific factors. Some general considerations are presented below.

- *Know your inks:* Evaluate your current ink system by considering all aspects of its use, including performance, worker and environmental risk, and costs. You can use this CTSA to determine whether chemicals present in your inks may present hazards and risks to your workers and the environment. Consider that choices of an ink system, and within that, the specific product lines and formulations, have many implications, some of which you may not have considered in the past. Another important source that can help provide this information is your ink supplier, who may be able to provide safety information specific to your inks.

- *Consider alternatives:* Use this CTSA to identify possibly safer ink alternatives and to help you determine whether you are using the best, safest, and most cost effective ink system for your facility's situation. You may also wish to discuss your options with ink suppliers, trade associations, technical assistance providers, other printers, and your customers.

- *Evaluate your current practices:* Even if you are using the safest ink possible, you may be increasing the risk to workers by using it inefficiently. As seen with the solvent- and water-based inks in this CTSA, solvent and additives added at press side increased the number of chemicals of clear worker risk. By minimizing or eliminating the need for these materials — using enclosed doctor blades and ink fountains, minimizing ink film thickness, and closely monitoring ink pH and viscosity — the risk to workers can be reduced. For presses with an oxidizer system, it is important to clean the catalyst when necessary and to keep the equipment operating at the optimum temperature so that it destroys as much VOC material as possible.

- *Protect workers:* Experienced and responsible employees are essential to a successful printing operation. Maintain their health and motivation by maximizing air quality and reducing the presence of hazardous materials. These steps may also yield savings with respect to regulatory and storage costs. You can also protect workers by ensuring that people who handle ink use gloves. Butyl and nitrile gloves are considered best for inks, and will minimize exposure to chemicals that may pose a health risk.

- *Look at all aspects of your printing operation:* Though this CTSA focuses on ink, several other steps in the flexographic printing process are sources of waste and candidates for process improvement. Read Chapter 7: Additional Improvement Opportunities for pollution prevention ideas that range from measures for particular process steps to facility-wide concepts. Systematic approaches, such as an Environmental Management System (EMS) or full-cost accounting, can help flexographers identify areas for improvement in their management of resources.

Ink Formulators and Suppliers

Ink companies have several important resources at their disposal: knowledgeable researchers, financial resources, and a communication network of sales representatives. Ink formulators have the ability to evaluate the feasibility of the substitution of different and safer chemicals, and can thoroughly test new formulations for performance characteristics. Supplier representatives have the ability to articulate the benefits of safer, better performing or less costly inks to printers.

- *Support environmental and health risk research:* Research is needed on several categories of chemicals:
    - ◊ those that are not regulated and pose risks
    - ◊ new chemicals (usually not regulated and not tested)
    - ◊ chemicals that have not undergone toxicological testing and have clear or possible risk concerns
    - ◊ high production volume chemicals[a]

  The point of such research is to ensure that the flexographic industry has access to as much information as possible about the chemicals they work with. Information is the most important key to improving inks.

- *Make improved ink safety a top goal of research and development:* The flexographic printing industry constantly demands new inks that can meet increasing performance needs. In addition to performance research, ink formulators can meet the needs of printers by looking for substitute ingredients that are less harmful to workers and the environment.

- *Communicate the safety aspects of inks with printers:* When sales representatives discuss different ink options with printers, inform the printers of any improvements in the environmental and worker risks associated with each product line. Because inks with minimized environmental and worker risks can result in cost savings as well as improved working conditions and less liability, printers may be interested in this information. Research has indicated that for printers, environmental and health risk issues are an important criteria when selecting an ink — second only to performance.[9]

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[a] High production volume (HPV) chemicals are manufactured in or imported into the United States in amounts greater than one million pounds per year. EPA has initiated a HPV Challenge Program to gather test data for all these organic chemicals (about 2,800). The CTSA includes 40 chemicals that appear on the HPV Challenge Program Chemical List.

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